https://doi.org/10.17895/ices.pub.18621962

Stock Annex: Anchovy (*Engraulis encrasicolus*) in Division 9a (Atlantic Iberian Waters)

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

Stock	Anchovy (*Engraulis encrasicolus*) in Division 9a (Atlantic Iberian Waters), (ane.27.9a_SA).
Working Group:	Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA).
Revised by:	WKPELA 2018.
Last benchmarked:	February 2018.
Last updated:	July 2018 (after ADGHANSA 2018).
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A. General

A.1. Stock definition

The European anchovy, *Engraulis encrasicolus*, is a small pelagic coastal marine fish, forming large schools, largely spread from the North Sea to SE Africa, including the entire Mediterranean basin. This species represents an important fishery and economic activity for the countries bordering the Iberian Peninsula and Mediterranean Sea (Uriarte *et al*., 1996; Lleonart and Maynou, 2002). Due to its market value, production, and wide distribution in several E Atlantic and Mediterranean countries, anchovy is a major shared resource in the region.

For management purposes, the European anchovy inhabiting the Atlantic waters were separated into two distinct stock units; one distributed in the Bay of Biscay (ICES Subarea 8) and the other distributed in ICES Division 9a (Spanish Southern Galicia, Portuguese coast and Spanish waters of the Gulf of Cadiz, GoC; **Figure A.1.1**), being the western part characterized by low abundances in most years and occasional outbursts of recruitment and the southern part of this area characterized by larger mean abundances more stable from year to year (South Atlantic Spanish waters). The stock limits were essentially based on administrative considerations, and the homogeneity of the 9a stock is questioned by several works pointing to a spatial discontinuity, and morphometric and genetic differences between the western and southern populations.

The distribution of anchovy in the ICES Division 9a (see **Figure A.1.1** for limits of each subdivision) is more stable in Subdivision 9a South, where about 83% of the population was encountered during the acoustic surveys (see **Section B.3**), mainly in the Spanish waters of the GoC (Figure A.1.2), which has decreased to 66% in the last decade. The distribution of anchovy eggs in the GoC is very similar to the adult distribution, suggesting that there are hydrodynamic mechanisms that function to retain the eggs in close proximity to the spawning grounds (see **Section A.3.3**). Also, the main concentration of eggs is found in the GoC and secondly in Subdivision 9a.CN and occasionally in the northern part of the 9a.CS. The distribution of both the eggs and the adult fish is remarkably similarly from year to year (low coefficient of variation), suggesting that the populations in the GoC and in the northwestern Iberia are both resident and that the spatial distribution is stable over time.

Figure A.1.1. Map showing the split of Division 9a into the stock components 9a South and 9a West. Note that, in turn, the stock *component* 9a South is divided into Portuguese and Spanish waters, whereas stock component 9a West is divided into the subdivisions 9a North, 9a Central–North, and 9a Central–South.

Outside these core habitats, resilient anchovy populations are usually detected in all fishery-independent surveys (ICES, 2018a; Garrido *et al*., 2018a) with previous records on large catches in the western component of the stock, mainly in ICES Subdivision Central–North, but also in subdivisions 9a North and 9a Central South and South (Algarve), suggesting that abundance in those areas have been high in early years of the time-series (Pestana, 1996; ICES, 1997; ICES, 2017a) and during the last decade as well. These western populations seem to be abundant when suitable environmental conditions occur, while during unfavourable conditions they seem to be restricted to the river and "rías" estuaries (Ré, 1984; Ribeiro *et al*., 1996; Ré, 1996). Thus, occasionally large catches are produced in 9a N, 9a C-N and 9a C-S, coincident with a sporadic raise up of the anchovy abundance in those areas, as for instance in 1995/1996, 2011 and 2015–2017 (ICES, 2017a).

In the south, outside the GoC, anchovy is abundant to the East of the Strait of Gibraltar, in the Mediterranean Sea (GFCM, 2002) as well as in northern Africa, where a combined Spanish-Morocco fishery produces landings of up to 12 000 t (Millán, 1992; García-Isarch *et al*., 2012).

ICES WGHANSA has traditionally concentrated its exploratory analysis on the anchovy in Subdivision 9a S, because it was the only persistent population in the area during the last three decades of surveys, while the western population has been mainly persistent during the last decade (see **Section H.1**). Data of species distribution, genetic and morphometric studies suggest that populations in the western Iberia have an independent dynamics from the anchovy population in 9a South. For this reason, the advice was, in the past, solely based on the information coming from the anchovy in 9a S (Algarve and GoC Spanish waters).

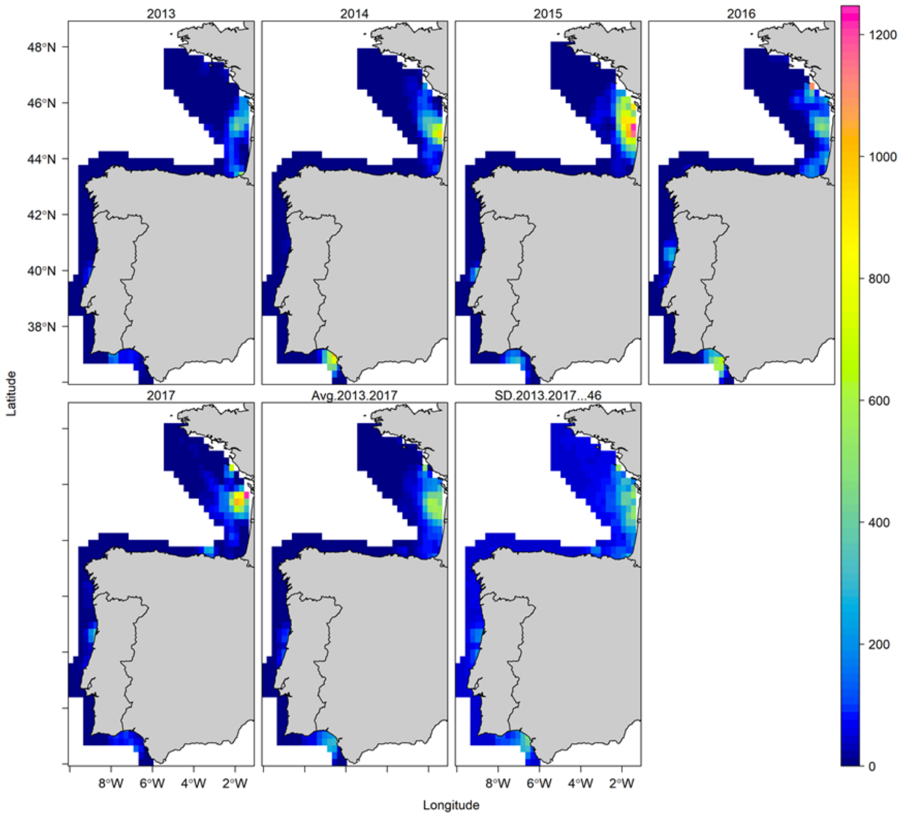

Figure A.1.2. Adult anchovy mean acoustic density (NASC, m² nm-²) maps derived from the *PELGAS*, *PELACUS* and *PELAGO* surveys, years 2013–2017, 0.25° map cell. "Avg.2013–2017": map of anchovy NASC values averaged over the series. "SD.2013–2017": map of anchovy NASC standard deviation over the series. Source: ICES 2018.

A review on the substock structure of the European anchovy in the Bay of Biscay and Iberian-Atlantic waters was first provided by Ramos (2015) to the ICES Stock Identification Methods Working Group (SIMWG) 2015 (ICES, 2015). This review revised the most recent studies on European anchovy genetics and morphometrics (body and otolith shape) and demonstrated that the European anchovy exhibits a complex population structure which has produced conflicting results in previous (and recent) genetic studies. Geographic studies of allozymes, microsatellites, nuclear DNA (nDNA) and mitochondrial DNA (mtDNA) have detected several genetic subdivisions among European anchovy populations. However, these studies have been limited in their power to detect some aspects of population structure by the use of a single or a few molecular markers, or by limited geographic sampling (see Zarraonaindia *et al*., 2012 and references therein).

Zarraonaindia *et al*. (2012) used a multi-marker approach, 47 nDNA and 15 mtDNA single nucleotide polymorphisms (SNPs), analysing anchovies from the whole range of the species distribution. This is the only work which analyses samples from all the different subdivisions of Division 9a except from the Algarve (9a S). Nuclear DNA analysis distinguished two groups: one from North Europe, Bay of Biscay and the Mediterranean Sea and the other including fish from the Atlanto-Iberian waters (9a) and the Alboran Sea. On the other hand, mitochondrial DNA analysis revealed genetic differences between anchovies from the western Iberia (9a N, C-N,C-S) and those from the Gulf of Cadiz (9a S).

Different genetic markers studies (nuclear-DNA, multiple SNP Markers, or allozymes) showed that the anchovy in the Alboran Sea are closely related to populations in the adjacent Gulf of Cadiz (Sanz *et al.*, 2008; Zarraonaindia *et al.*, 2012, Silva *et al.* 2014) or Canary Islands archipelago (Bouchenak-Khelladi *et al.*, 2008; for samples from Southern Alboran). Sanz *et al.* (2008) and Zarraonaindia *et al.* (2012) showed that anchovies in the Alboran Sea are more closely related to populations in the adjacent Gulf of Cadiz than to other Mediterranean populations, suggesting that these two stocks represent a meaningful management unit that should be dealt as a single stock. On the other hand, Viñas *et al.* (2014) indicates that Gulf of Cadiz and Alboran Sea anchovy populations are genetic units clearly separated. Therefore, the stock identity of these two populations is still unclear.

This genetic subdivision observed in Ibero-Atlantic coasts was in concordance with the morphological segregation pattern described by Caneco *et al.* (2004). That study suggests a clear separation between anchovies from the Bay of Biscay (ICES subareas 8b, 8c) and those from Division 9a (these latter ones with a larger head, smaller medium-posterior body dimensions, larger dorsal fin base length), as well as a north–south cline along the Portuguese and Gulf of Cadiz area, with fish from the Gulf of Cadiz being mostly different (higher head-to-body ratios) from those in northern 9a area. According to the authors, such differences between areas could reflect slight adaptive reactions to small environmental differences.

With all these evidences at hand, SIMWG (ICES, 2015) considered at that time that there was evidence to support a self-sustained population of anchovy located in the GoC (ICES Subdivision 9a South), but there was a lack of information regarding the origin of European anchovy in ICES 9a West (comprising subdivisions 9a North, 9a Central-North and 9a Central-South).

An updated review on the substock structure of the European anchovy in Iberian waters was provided to WKPELA 2018, which included new information that could bring light into the origin of the populations of the 9a West subdivisions (Garrido *et al.*, 2018a). Thus, data of the spatial distribution of anchovy in Division 9a provided by surveys have shown a persistent discontinuity of the western and southern components of the stock for several life stages (eggs, juveniles and adults) and during different seasons of the year, when research cruises cover the whole 9a Division (spring, fall) or the entire Portuguese waters (summer). Landings also show this discontinuity, with e.g. more than 90% of Portuguese landings occurring in Subdivision 9a CN in 2017.

Moreover, no correlation was found between anchovy catches between the West and South components, further suggesting independent dynamics. The hypothesis that the Western stock might come from migration from the southern component was not supported by the current data, since there was no correlation between anchovy abundance or landings in the western Iberia with anchovy abundance in the southern Iberia in the previous year. On the contrary, anchovy landings on the west coast were significantly related to the abundance of the species in that area, demonstrating the independent dynamics of anchovy fishery for the two components. Several studies conducted in Portuguese estuaries (Ribeiro *et al.*, 1996; Pombo *et al.*, 2002; Chícharo *et al.*, 2006; Marques *et al.*, 2006; Ramos *et al.*, 2006; Cardoso *et al.*, 2011; França *et al.*, 2011; Chícharo *et al.*, 2012; Nyitrai *et al.*, 2012) have also shown the persistent presence of recruits in numerous estuaries, mainly in the Subdivision 9a CN, which, agreeing with the concentration of eggs in this subdivision, points to the presence of a self-sustained population in this area. As described above, morphometric and genetic studies indicate a separation of the western and Cantabrian populations, as well as a separation with those from the GoC, while the separation of the population from the GoC and the Alborán Sea (Spanish SW Mediterranean) is still unclear.

These evidences has led to ICES WGHANSA to propose the anchovy populations inhabiting the southern (9a South) and western (9a North, Central-North and Central-South) Iberian regions in Division 9a as separate stock units for management purposes, suggesting the provision of separate advice for both units (**Figure A.1.1**). WKPELA 2018 supported the proposal of considering two different components of the stock (western and southern component) for which the advice should be given separately, but evidences were not consensually considered sufficient to modify the current stock structure. However, it was suggested to present both the available evidence provided to WKPELA 2018 and new evidences of undergoing genetic and morphometric studies to the ICES Stock Identification Methods Working Group for future consideration.

A.2. Fishery

A.2.1. General description

The anchovy fishery in Division 9a is harvested by Spain (in subdivisions 9a North and 9a South, Spanish waters of the GoC) and Portugal (in subdivisions 9a Central-North, 9a Central-South and 9a South, Algarve).

A.2.1.1. Western component

The Portuguese and Spanish purse-seine fleets (PS_SPF_0_0_0) account on average for more than 95% of total catches of anchovy coming from the Western area, although the bulk of anchovy catches mainly comes from the Portuguese fishery in 9a Central-North (Garrido *et al.*, 2018b). These fleets mainly target sardines, but in recent years has been targeting other pelagic fish species, due to restrictions to sardine fisheries, such as chub (*Scomber colias*) and horse mackerel (*Trachurus trachurus*) and, occasionally during some years, also anchovy (Silva *et al.*, 2015). Incidental catches are also landed by Spanish and Portuguese bottom trawl (OTB_DEF_> = 55_0_0) and artisanal polyvalent vessels (MIS_MIS_0_0_0_HC). Discards are considered negligible.

A.2.1.2. Southern component

The Spanish purse-seine fleet (métier PS_SPF_0_0_0) is the main responsible for the anchovy fishery in Subdivision 9a South, accounting for 95% of the total anchovy landings on average for the recent fishery (Ramos *et al.*, 2018). The Spanish bottom-trawl fleet (OTB_MCD_> = 55_0_0) is the following fleet in importance (approximately 3% on average), but such contribution was mainly restricted to the second half of the nineties, when this fleet fished anchovy as bycatch. The Portuguese purse-seine fleet only contributes with 2% of total catches on average. Incidental catches are also landed by Portuguese bottom-trawl (OTB_DEF_> = 55_0_0) and artisanal fleets using artisanal purse-seines (also termed in their national statistics as “polyvalent” vessels; MIS_MIS_0_0_0_HC). Discards are considered negligible.

Traditionally anchovy and sardine are the main target species for the Spanish and Portuguese purse-seine fleets, respectively. Silva *et al.* (2007) identified a clear seasonality in the Spanish purse-seine fishery, characterized by a sequential occurrence of anchovy and sardine fishing trips through the year, with trips targeting anchovy being dominant during spring–summer and those ones targeting sardine being more frequent from late summer to late winter, seasons coincident with the spawning seasons of these target species in the area.

A.2.2. Fishery management regulations

No EU management plan exists for the anchovy fisheries in Division 9.a. The regulatory technical measures in force for the Spanish (ES) and Portuguese (PT) anchovy purse-seine fishing in the Division 9a (since mid-1980s) are summarized as follows (see also pil.27.8c9a Stock Annex for the Portuguese fishery):

- Minimum landing size:
    - 9a N (ES), 9a CN-9a CS-9a S (PT): 12 cm.
    - 9a S (ES): 10 cm.
- Minimum vessel tonnage: of 20 GRT with temporary exemption (ES).
- Maximum engine power: 450 hp (ES).
- Purse-seine maximum length: 450 m (9a S, ES); 600 m (9a N, ES); 800 m (PT).
- Purse-seine maximum height: 80 m (9a S, ES); 130 m (9a N, ES) 150 m (PT).
- Minimum mesh size: 14 mm (ES); 16 mm (PT).
- Fishing time: 5 days per week (PT, ES).
- Seasonal closures:
    - PT (for sardine): 1.5–2 months (winter/spring) in 9a CN. Since 2015 in 9a CN-9a CS-9a S.
    - ES (for anchovy): voluntarily 3 months (December–February; until 1997), 1.5 months (November–December 2004–2005), 2 months (November–December 2006), 3 months (November–February 2007–2008), 1 month (December 2009–2010), 2 months (December–January 2011 on) in 9a S, under different GoC purse-seine fishery management plans.
- Spatial closures:
    - PT: ¼ nm distance to the coastline. 1 nm if below 20 m depth.
    - ES: inside bays and estuaries and internal waters in 9a N and 9a S. A Marine Protected Area, MPA (the Guadalquivir River mouth fishing reserve) was created in June 2004 in 9a S (**Figure A.2.2.1**). The protected area corresponds to the main nursery area of fish (including anchovy) and crustacean decapods in the GoC. Fishing in the reserve is only allowed (with pertinent regulatory measures) to gillnets and trammelnets, although outside the riverbed. Neither purse-seine nor bottom-trawl fishing is allowed all over this MPA.

Between 2006 and 2012 Spain implemented successive GoC purse-seine fishery management plans (9a S, ES). A new regulation approved in October 2006 established that up to 10% of the total catch weight could be constituted by fish below the established minimum landing size (10 cm) but fish must always be ≥9 cm.

Since April 2013 Spain implemented a new management plan for fishing vessels operating in its national fishing grounds, so it affects the purse-seine fishing in Galician (9a N) and GoC Spanish waters (9a S (ES)). One of the main measures in this new plan is the introduction of an individual quota (IQ) system to allocate annual national quotas.

In the case of the GoC purse-seine fishery this measure involves to shift from a system of a fixed daily catch quota system for all the fleet to a new one based on the implementation of a IQ system managed quarterly by each fishery association after resolution of the National Fishery Administration on the annual allocation of the national quota by association.

By way of from Article 15(1) of Regulation (EU) No 1380/2013, which aims to progressively eliminate discards in all Union fisheries through the introduction of a landing obligation for catches of species subject to catch limits, the purse-seine fishery in ICES zones 8, 9. and 10 and in CECAF areas 34.1.1, 34.1.2 and 34.2.0 targeting anchovy has a final *de minimis* exemption to the quantities that may be discarded of up to a maximum of 2% in 2015 and 2016, and 1% in 2017, of the total annual catches of this species. STECF concluded that this exemption is supported by reasoned arguments, which demonstrate the difficulties of improving the selectivity in this fishery. Therefore, the exemption concerned has been included in the Commission Delegated Regulation (EU) No 1394/2014 of 20 October 2014 establishing a discard plan for certain pelagic fisheries in southwestern waters.

Finally, the joint recommendation includes a minimum conservation reference size (MCRS) of 9 cm for anchovy caught in ICES Subarea 9 and CECAF area 34.1.2 with the aim of ensuring the protection of juveniles of that species. The STECF evaluated this measure and concluded that it would not impact negatively on juvenile anchovy, that it would increase the level of catches that could be sold for human consumption without increasing fishing mortality, and that it may have benefits for control and enforcement. Therefore, the MCRS for anchovy in the fisheries concerned should be fixed at 9 cm.

Figure A.2.2.1. Ane.27.9a stock. Anchovy fishery in Subdivision 9a South. Limits of the Fishing Reserve off the Guadalquivir River mouth (Spanish waters of the Gulf of Cadiz).

A.3. Ecosystem aspects

A.3.1. Species interactions effects

Anchovy is a prey species for other pelagic and demersal species, and for cetaceans and seabirds (Torres *et al*., 2013).

A.3.2. Ecosystem effects of fisheries

The purse-seine fishery is highly mono-specific, with a low level of reported bycatch of non-commercial species. Information gathered from observers at sea sampling programmes and interview-based surveys indicate, at least for the western waters of the Iberian Peninsula façade, a low impact on the common dolphin population (Wise *et al*., 2007), but less data are available on seabird and turtle bycatch. Other species such as pelagic crabs are released alive and it is likely that the inflicted mortality is low.

A.3.3. Ecosystem drivers

A.3.3.1. Western component: The Western Iberia Upwelling Ecosystem

The Western Iberia Upwelling Ecosystem (WIUE, Santos *et a*l., 2007; **Figure A.3.3.1.1**) is located at the northernmost limit of the Canary Current Large Marine Ecosystem and is comprised of several subregions distinguishable by their coastline morphology, freshwater input, exposure to prevailing winds and dominant water masses (Mason *et al*., 2005): i) the northern Iberian shelf, characterized by a narrow shelf with summer upwelling events limited to the west (Galicia; Subdivision 9a N); ii) the western Iberian shelf (subdivisions 9a CN and 9a CS), characterized by a wide platform and high river run-off, particularly off the northwest coast, wider platform, and a narrower shelf towards the south, both exposed to frequent and intense spring/summer upwelling events.

In the western component (subdivisions 9a N, 9a C-N y 9a C-S), anchovy distribution is mainly associated with the main Portuguese estuaries, located in Subdivision 9a C-N. This subdivision is the main area of distribution of anchovies, and larvae and recruits are frequently found inside, or in the vicinity of, estuaries (e.g. Ramos *et al*., 2006; Marques *et al*., 2006; França *et al*., 2011). In the Subdivision 9a C-S anchovies are also frequently found spawning in the estuaries, namely Tejo and Mira (e.g. Ré, 1984; 1996). It was also demonstrated that the combined effect of a low salinity plume and a poleward current during winter upwelling events creates the proper conditions for retention of egg and larvae close to the shelf break favouring some population outbursts (Santos *et al*., 2004).

Conversely, extreme events of offshore transport of phytoplankton inside long filaments (≈400 km) induced by eddy–eddy interactions occur in SW Iberia (Subdivision 9a C-S; Peliz *et al*., 2004). The estimated offshore water transport of one of these events was about 58 km^3 day^{-1} with a development time of 20 days, and corresponding to a phytoplankton biomass transport of 8 t day^{-1}. These conditions lead to a dramatic phytoplankton growth inside the filament, enriching the oligotrophic oceanic waters. The magnitude of these extreme events can be several times larger than recurrent upwelling-generated filaments, *i.e*. 890 t of phytoplankton (Peliz *et al*., 2004) against 70 t (Cravo *et al*., 2006). The frequency of occurrence of these extreme phenomena is unknown. However, this intense mesoscale activity observed in the SW Iberia could explain why this is not considered a favourable recruitment area for sardine (Bernal *et al*., 2007) and other species. In that area, the shelf is narrow and intense eddy activity is observed, thus these factors could contribute to enhance cross-shelf exchange and be responsible for the observed larval absence.

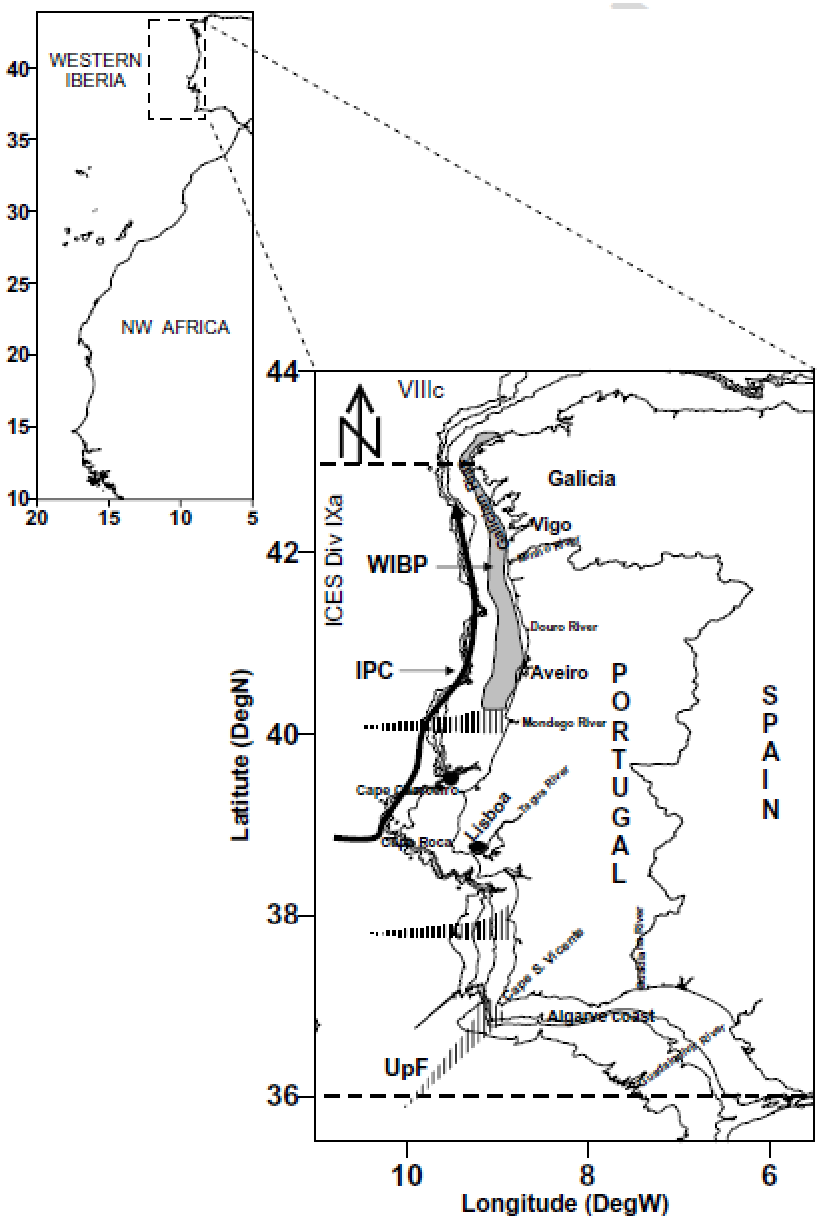

Figure A.3.3.1.1. The Western Iberia Upwelling Ecosystem (WIUE). The small map represents the whole Canary Current Upwelling System, in which the location of the WIUE is represented by the dashed rectangle. WIBP: the Western Iberia Buoyant Plume; IPC: the Iberian Poleward Current; UpF: upwelling filaments. The isobaths of the 200, 500 and 1000 m are also presented to locate the shelf break. ICES Divisions are also presented and their limits are represented by the dash straight lines. Source: Santos *et al*. (2007).

Garrido *et al*. (2017) explored the relationships between satellite-derived SST and Chl_a and Iberian sardine recruitment. A similar approach, although based on a smaller dataset, attempted with the western anchovy demonstrates a relatively high correlation between the maximum Chl_a concentration estimated during the peak spawning season (April-May for the western populations according to Ré, 1996) and the subsequent recruitment, as estimated as the abundance of fish <12 cm (roughly first year of life) by the *PELAGO* spring acoustic survey of the following year for the same area (S. Garrido, personal communication). These relationships will be further explored, to try to understand the environmental conditions related to anchovy outbursts (and low abundances) on the west coast.

A.3.3.2. Southern component: The Gulf of Cadiz

The Gulf of Cadiz (GoC) is a subbasin between the Iberian Peninsula and the African Continent that connects the Atlantic Ocean and the Mediterranean Sea through the Strait of Gibraltar. The northern half of the GoC is the southernmost Atlantic European regional sea.

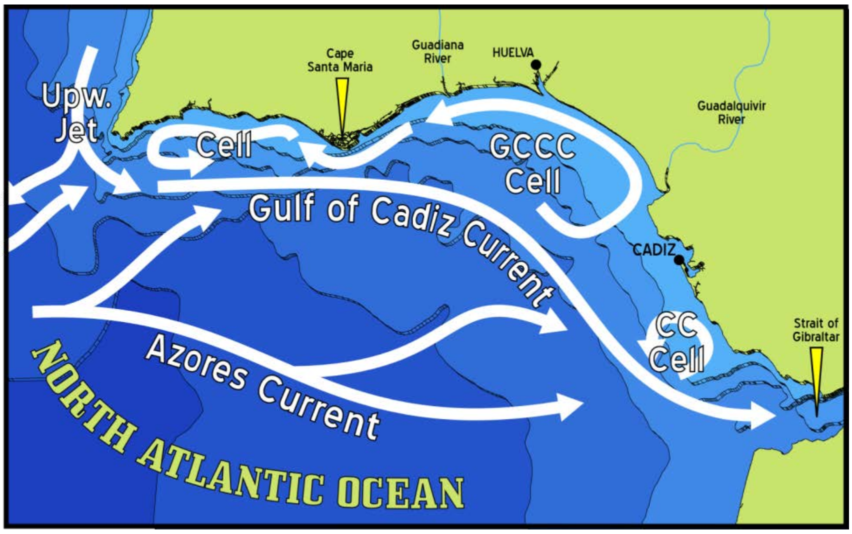

Figure A.3.3.2.1. Surface circulation in the GoC. CC Cell: cyclonic cell over the shoals in front of Cape Trafalgar; GCCC Cell: Gulf of Cadiz Countercurrent; Upw. Jet: Portuguese upwelling. Source: Ricardo Sánchez-Leal *pers. comm.* (after Folkard *et al.*, 1997; Peliz and Fiuza, 1999; Relvas and Barton, 2002; Sánchez and Relvas, 2003; Criado-Aldeanueva *et al.*, 2006; García-Lafuente *et al.*, 2006; Sánchez *et al.*, 2006; Peliz *et al.*, 2009).

The GoC is placed in the northern area of the Canary Current Large Marine Ecosystem, and shares many of the oceanographic characteristics typical of the Eastern Boundary Upwelling Systems (EBUSs) in middle latitudes (e.g. seasonal alternation of a regime of winds favourable to the coastal upwelling, a high biological productivity associated to this process, a system of zonal fronts and currents, and a coastal transition zone with a set of mesoscale structures that deform the fronts favouring the coast-open ocean exchange). Its main distinctive features are (Figure A.3.3.2.1): i) the rupture at Cape São Vicente of the N–S orientation of the coastline typical of the EBUSs by an E–W orientated coastline, which frees most of the GoC from the tight control of the upwelling regime off Portugal (Fiúza, 1983; Relvas and Barton, 2002). This is particularly true to the east of Cape Santa Maria, where the influence of the Portuguese upwelling vanishes, the shelf widens and waters here reach the highest temperatures in the region; ii) the influence of a northern branch of the Azores Current; iii) the presence of the Strait of Gibraltar with its Atlantic-Mediterranean water exchanges and mixing, and iv) the seasonality, that produces alternant regimes in the surface waters and an intense generation of mesoscale, which modulate and are modulated by the exchange in the Strait (see e.g. García-Lafuente and Ruiz, 2007; Sánchez *et al.*, 2006; ICES, 2012a).

Cape Santa Maria divides the GoC shelf in two sectors that support different oceanographic processes (forcing by mass and energy inputs and tidal processes) causing that the eastern shelf is warmer and more productive than the western one, which is subject to a more permanent upwelling (Navarro and Ruiz, 2006; Prieto *et al*., 2009). In this eastern sector, shallower and with a lower intensity of currents, the Guadalquivir estuary also plays a relevant role (by constant tidal mixing) in the control of the biological activity on the shelf.

Despite the dynamism of all these processes that include mesoscale upwelling, internal waves or tidal mixing, the input of nutrients from freshwater discharges from the estuary of Guadalquivir River dominates as it is the main driver of the primary production in the GoC (Navarro and Ruiz, 2006; Prieto *et al*., 2009). Inputs from the estuary of Guadalquivir River connect human and natural forcing as well as land and marine ecosystem dynamics in the region. Thus, human regulations of freshwater from a network of reservoirs tightly control the regime of primary production both within the estuary and in the adjacent areas (Ruiz *et al*., 2017a), with consequences on the trophic flow and the recruitment of mid-trophic species like anchovy (Ruiz *et al*., 2006) in a process facilitated by the saltmarshes in Doñana natural area which act as a nursery region for many marine species (Drake *et al*., 2002; 2007; Baldó *et al*., 2006; Ruiz *et al*., 2006; González-Ortegón *et al*., 2010; 2012).

The presence of the Guadalquivir estuary and marshes together with the tidal forcing generate a pool of warm water off the river mouth during spring and summer (García-Lafuente *et al*., 2006; García-Lafuente and Ruiz, 2007). The tidal forcing and the river flow also contribute to maintaining high nutrient and chlorophyll levels all year-round, which is particularly important in summer, when the rest of the basin is stratified and oligotrophic. These particular conditions make the area off the Guadalquivir the most productive of the GoC (Navarro and Ruiz, 2006). Traditionally, the local cyclonic surface circulation pattern described during spring–summer, has been put forward as a favourable mesoscale feature with regard to the maintenance of this warm and productive cell (García-Lafuente *et al*., 2006; Criado-Aldeanueva *et al*., 2006; 2009; Garel *et al*., 2016).

Studies arising from a Guadalquivir estuarine monitoring program since 1997 have described long-term changes in anchovy early life stages and other nekton components in relation to salinity and turbidity conditions (Drake *et al*., 2007; González-Ortegón *et al*., 2010; 2012). The nursery function is the main regulating service the region provides in relation to the GoC fisheries. It is this estuarine factor, where terrestrial and marine processes converge, that makes the GoC a unique case study (Ruiz *et al*., 2015; Llope, 2017).

For these reasons, these shelf waters of the NE GoC, mainly those ones in the inner shelf surrounding the Guadalquivir River mouth, offer a favourable environment for the development of anchovy eggs and larvae in spring–summer and become in the main GoC anchovy spawning area (Baldó *et al*., 2006). The outer stretch of the Guadalquivir estuary is used almost synchronously by anchovy post-larvae and juveniles as a nursery area. Recruitment to the estuary occurs when water temperature and salinity are relatively high, but turbidity and rainfall are relatively low. Some studies (Baldó and Drake, 2002; Drake *et al*., 2007; Fernández-Delgado *et al*., 2007; González-Ortegón *et al*., 2010) point out that, within this optimal window, the main factor regulating the nursery function of the estuary is the food availability of key-prey species (copepods for post-larvae, the mysid *Mesopodopsis slabberi* for juveniles).

There is a local upwelling regime to the west of Cape Santa Maria, which is independent of that of the Canary Current and considered a coastal process with a short time response to changes in the wind regime (Criado-Aldeanueva *et al*., 2006). Westerlies are the winds responsible for upwellings while easterlies have the opposite effect leading to a remarkable increase in temperatures (Prieto *et al*., 2009). Furthermore, the westerlies/easterlies regime plays a central role in the continental shelf dynamics of the area, affecting retention within the warm cell. Under westerlies conditions, local upwellings enhance productivity and plankton is confined inside the cyclonic cell. In contrast, easterlies would favour oligotrophy and the westward advection of plankton and larvae (Relvas and Barton, 2002; Catalán *et al*., 2006). Thus, persistent spring and early summer easterlies bursts (preceded and followed by intervals of a lower frequency of this wind) may generate significant modifications in the oceanographic regime in the GoC (*i.e.* decrease of SST, oligotrophy, offshore advection of early stages away from favourable conditions), which can markedly influence the reproductive success of the species. These detrimental conditions were evident during the period 1990–1997 and they seemed to affect to the development conditions of anchovy eggs and larvae, which could result in failed recruitments in those years as evidenced by the severe drop of landings in 1995–1996 (Ruiz *et al*., 2006; 2009; **Figure A.3.3.2.2**). According to the authors, this drop of landings resembled more the easterly signal than the NAO index or precipitation. Conversely, the 1996 rain fall peak (and associated river discharges), clearly reflecting the dramatic change in the NAO index, may have played a role in the recovery of 1997 anchovy landings.

The GoC anchovy population also experienced a noticeable decreasing trend during the period 2008–2010 as a probable consequence of successive fails in the recruitment strength in those years (ICES, 2011). A man-induced alteration of the nursery function of the Guadalquivir estuary, caused by episodes of highly persistent turbidity events (HPTE; González-Ortegón *et al*., 2010), during the anchovy recruitment seasons in 2008, 2009 and 2010 could be one plausible explanation. Thus, the control of the Guadalquivir River flow, from the Alcalá del Río dam 110 km upstream, has an immediate effect on the estuarine salinity gradient, displacing it either seaward (reduction) or upstream (enlargement of the estuarine area used as nursery). Also affects to the input of nutrients to the estuary and adjacent coastal areas. The abovementioned HPTEs used to start with strong and sudden freshwater discharges after relatively long periods of very low freshwater inflow and caused significant decreases in abundances of anchovy juveniles and the mysid *Mesopodopsis slabberi*, its main prey (**Figure A.3.3.2.3**).

As a short-lived small pelagic species, anchovy population dynamics is strongly affected by year-to-year fluctuations in environmental processes. As described above, temperature, winds and discharges from the Guadalquivir River have been identified as key factors influencing its recruitment (Ruiz *et al*., 2006; 2009; Rincón *et al*., 2016). Discharges have different effects on the nursery role depending on their volume. Low levels of freshwater discharges constrain primary productivity on the shelf limiting the food supply for juveniles (Prieto *et al*., 2009) while very high discharges cause salinity to drop below the threshold forcing juveniles to leave the protective environment of the estuary (Ruiz *et al*., 2009). However, the combination of both natural (weather) and anthropogenic (discharges) effects, plus the timing and volume discharged, results in a broad range of combinations that makes the ecological response of the ecosystem to freshwater inputs be not unequivocal (González-Ortegón and Drake, 2012; González-Ortegón *et al*., 2012; 2015).

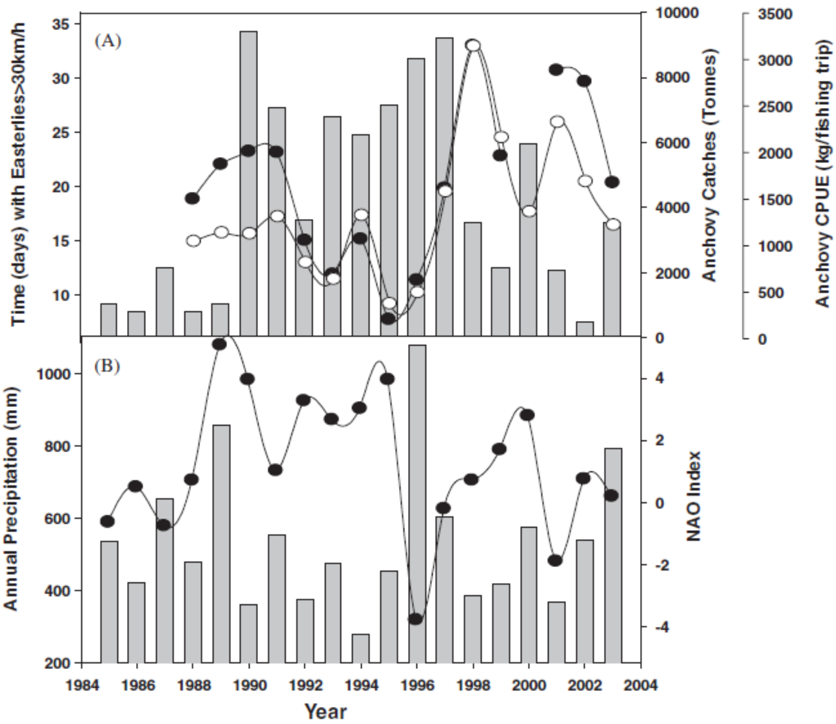

Figure A.3.3.2.2. A. GoC anchovy landings (ICES Subdivision 9a South; black circles) and Barbate's single-purpose purse-seine fleet cpue (white circles, in kg/fishing trip). Barbate is considered as a reference fleet in the GoC anchovy harvesting. Landing data for 2000 is not included in the graph as catches were not representative due to social conflicts in the fleet. Bars accumulate the time when easterlies stronger than 30 km/h hit Cádiz over the period from March to September. B. Circles and bars indicate North Atlantic Oscillation index and annual precipitation, respectively. Source: Ruiz *et al.* (2006).

In the last years, models including environmental information have been developed by means of Bayesian simulation techniques (Ruiz *et al.*, 2009; 2017b; Rincón *et al.*, 2016; 2018), GAM empirical modelling (Carvalho-Souza *et al.*, in prep.), as well as mass-balanced models describing the role of GoC anchovy in the marine foodweb (Torres *et al.*, 2013). An ecosystem approach perspective is presented in Llope (2017) (see also ICES, 2017b).

All of these evidences confirm that the GoC anchovy stock relies on recruits to persist and, therefore, is highly vulnerable to ocean processes and controlled by fluctuations in both environmental and anthropogenic variables.

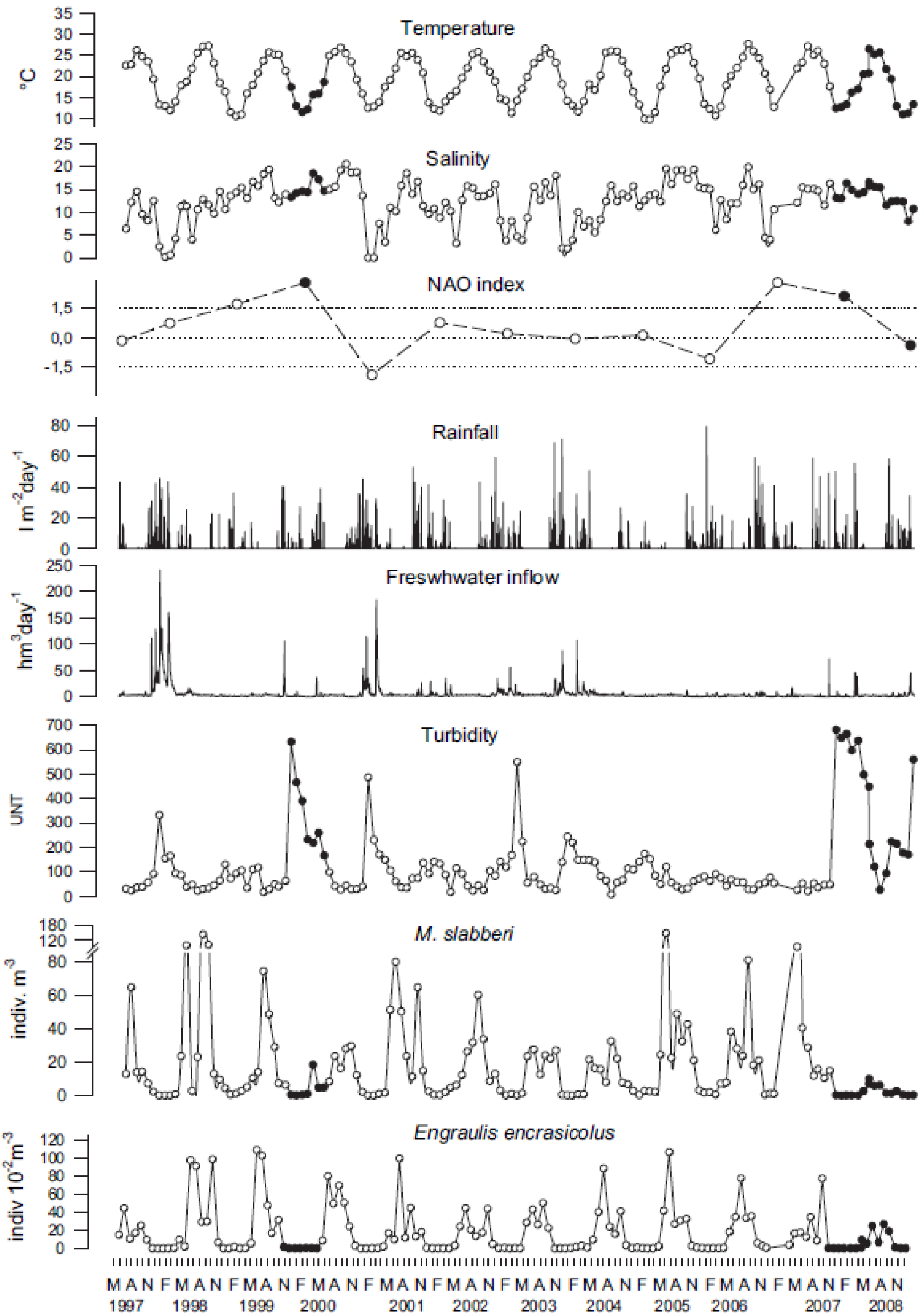

Figure A.3.3.2.3. Monthly/daily mean values of environmental variables (water temperature, salinity, rainfall, freshwater inflow, and turbidity), mysids and anchovy recruits' densities in the Guadalquivir Estuary from May 1997 to February 2009, and winter NAO index values for the same period. F, February, M, May, A, August, N, November. Shaded symbols, samples collected during HPTEs (composite figure from González-Ortegón *et al.*, 2010).

B. Data

B.1. Commercial catch

B.1.1. Landings

Landings data are collected by the Spanish and Portuguese government official entities responsible for fisheries data (General Fisheries Secretariat in Spain, General Fisheries Directorate in Portugal). For the recent fishery, the official landings statistics are the result of the cross-checking of first sale notes and logbooks (which are mandatory for vessels larger than 10 m in the Spanish fishery since 2004). These statistics cover the whole stock area. In both countries landings are not considered to be significantly under reported. Commercial catch data are then obtained from the national laboratories of both Spain (IEO) and Portugal (IPMA), and provided to the ICES WGHANSA by subdivision/quarter/métier.

Up to 1990, landings were reported by three stock areas (Spain–8c, Spain–9a, and Portugal–9a). Since 1991, both Spanish IEO and Portuguese IPMA (former IPIMAR) have used a common Excel Workbook (the Data Submission Work Book) to provide all necessary annual landings and sampling data (on a quarterly basis), which was originally developed for the former ICES Working Group on the Assessment of Mackerel, Horse-mackerel, Sardine and Anchovy (WGMHSA). These data were disaggregated in five subareas (8c E, 8c W, 9a N, 9a C-N, 9a C-S, 9a S (Portugal), 9a S (Spain)). It should be noted that only sampled, official, WG catch are available in this file. In more recent years, commercial catch and sampling data are uploaded in the InterCatch software by the respective national submitters and then processed by the stock coordinator using this same software.

B.1.1.1. Western component

The Portuguese statistics of annual landings date back to 1943 (Pestana, 1996; ICES, 1997; Garrido *et al*., 2018), while Spanish annual landings are available since 1989 (see next subsection). Large populations in Galicia and Portugal have historically supported large harvests until the early 1960s when these populations declined (Junquera, 1986; Pestana, 1989; 1996; **Figure B.1.1.1**).

B.1.1.2. Southern component

As described above, the Portuguese annual landings statistics date back to 1943. Spanish annual landings started to be available since 1989 because of the mixing of catches coming from the Spanish and Moroccan fishing grounds in the official fishery statistics until that year. Therefore, a complete coverage of catch statistics for the entire Subdivision 9a South is only available for the post-1989 fishery (Ramos *et al*., 2018; **Figure B.1.1.1**). This time-series of catches (1989–2016) has been the initially considered one in the proposed analytical assessment with the Gadget model.

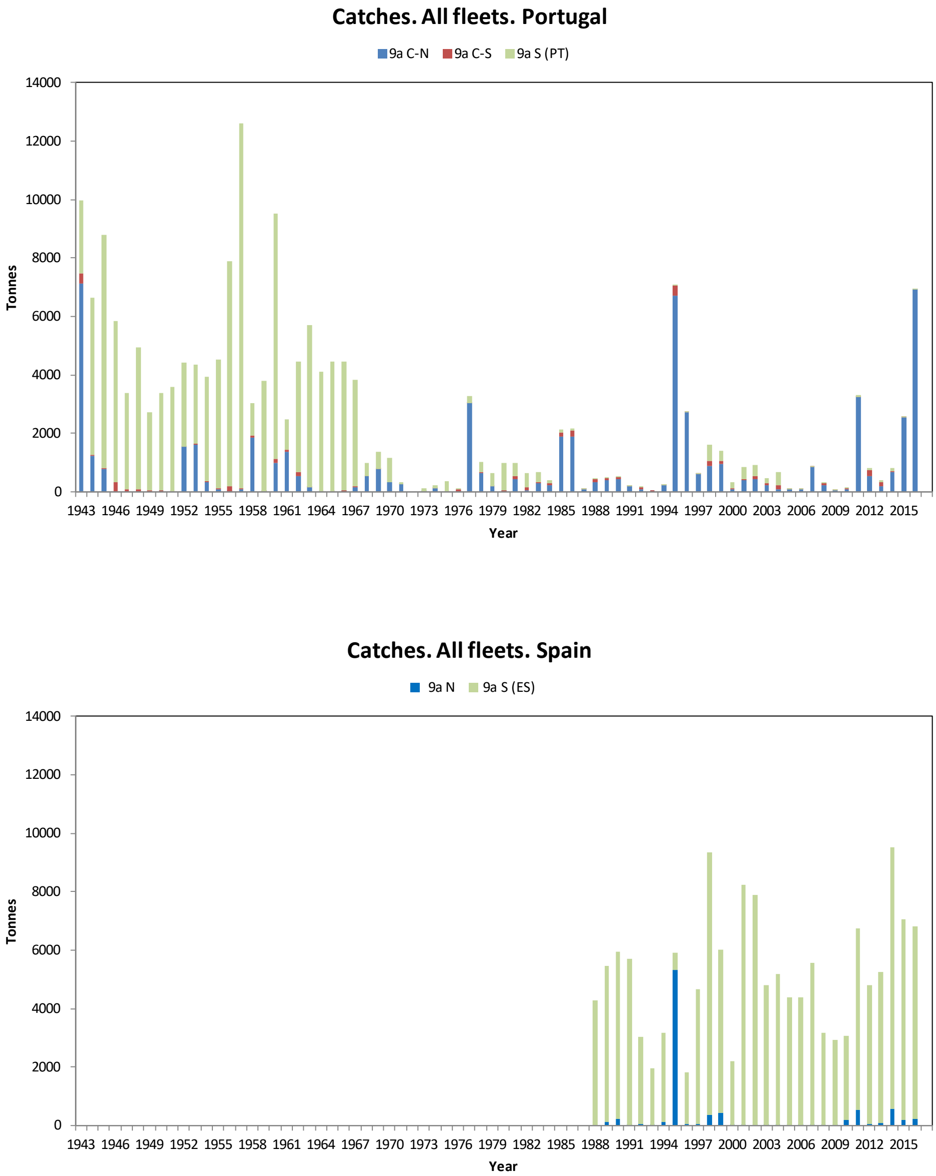

Figure B.1.1.1. Anchovy fishery in Division 9a. Anchovy catches (all fleets, in tonnes) in the Portuguese (top) and Spanish (bottom) fisheries by subdivision (1943–2016). Source: ICES (2017a).

B.1.2. Discards estimates

Discards are sampled by Portugal and Spain within their respective EC-DCR-based National Sampling Schemes. Discard sampling strategies and methods follow those adopted by the ICES Workshop on Discard Sampling Methodology and Raising Procedures (ICES, 2004). The actual magnitude of discarding practices for the past anchovy fishery in the Division 9a is unknown.

B.1.2.1. Western component

The respective DCF national sampling programs have revealed for the recent fishery (since the early 2000s) that, in general terms, anchovy discards may be considered as negligible or even null. Anchovy discards in the Portuguese fishery are considered null, therefore for the Portuguese fishery landings = catches. Discards in the Spanish fishery in 9a N are estimated since 2014, when the sampling coverage was sufficient to provide reliable estimates: in 9a N discards are almost zero (discards ratios have oscillated for the period 2014–2016 between 0 (0%)–0.001 (<0.1%)).

B.1.2.2. Southern component

Since 2004 official information provided to ICES states that there are no anchovy discards or they are negligible in the Portuguese fishery in the Gulf of Cadiz. Therefore, landings can be equalled to catches. Data on anchovy discarding in the Spanish fisheries operating in 9a South started to be gathered on a quarterly basis since the fourth quarter in 2005 on. However, the low sampling intensity applied until 2013 to assess the anchovy discarding resulted in unreliable and not representative quarterly discard estimates which were also affected by high CVs and hence they were not considered. Since 2014 on a more intense sampling scheme was developed which also extends to the Spanish fishery in Subdivision 9a North. Overall annual discard ratios estimated since 2014 oscillate between 0.01 (1%)–0.026 (2.6%), hence anchovy discards can also be considered as negligible in the Spanish fishery in the 9a South. Notwithstanding the above, since 2014, discards are estimated by quarter/métier/size/age and aggregated to landings to provide catches.

B.2. Biological

B.2.1. Length, weight and age composition of anchovy landings and discards in commercial fisheries

B.2.1.1. Western component

Length–frequency distribution (LFD) of catches and catch-at-age data from the western component of Division 9a are not available on a regular basis, given that historically, commercial landings were low and sporadic. The increase of anchovy abundance in the last decade has led to an increase in the exploitation of the species by the fleets operating in those areas and more data of quarterly LFDs has been provided for the Spanish and Portuguese fishery in subdivisions 9a N and 9a C-N, respectively. Given the low abundance of anchovy in Subdivision 9a C-S, even in recent years, the availability of anchovy length data for that area is extremely low. Regarding the age structure of the catches, only data from the Spanish fishery (9a N) is available; no age structure is available for the Portuguese anchovy catches (Garrido *et al*., 2018).

B.2.1.2. Southern component

The sampling coverage and intensity of the length frequency distribution (LFD) of landings are very different for the Portuguese and Spanish fisheries and depends on the resource availability and commercial interest. Thus, anchovy is not a priority fishing species for the Portuguese fishery in 9a South, unless it is abundant, and this fact is reflected in the almost null LFD availability throughout the period under analysis. Conversely, anchovy is the target species for the Spanish fishery in this subdivision. LFDs are available since 1989. During the period 1989–2008 LFDs were sampled in fishing harbours, between 2009 and 2013 from a concurrent sampling both in land and at sea, and since 2014 on, from a concurrent sampling directly at sea. For the whole period under analysis, the sampled raw LFDs of landings correspond to the purse-seine fishery, the main responsible for the Spanish anchovy fishery in the subdivision. These raw LFDs are sampled on a monthly basis, raised to monthly total landings and then pooled and provided by quarter and year to ICES. LFDs from bottom-trawl landings (which occurred between 1993 and 2012, especially between 1993 and 2000; Ramos *et al*., 2018) were not sampled because their relatively low representativeness in the whole fishery (not higher than 18% in those years with the highest landings). Those LFDs for the period 1989–2013 were estimated raising the purse-seine LFD to the total catches (catches from all fleets pooled) by assuming the abovementioned scarce representativeness of the other métiers than purse-seine.

Since 2014, quarterly LFDs from discarded catch are sampled by métier in the Spanish fishery, and raised to total estimated discards; then pooled to the quarterly LFDs of landings to derive the LFD of quarterly and annual catches.

It is acknowledged that ageing anchovy otoliths from Division 9a is very difficult. During the last workshop on otolith exchange for anchovy age reading (ICES, WKARA 2, ICES, 2017c) it was suggested threshold values of agreements around 80% and of CVs around 20% in the training process as a minimum for age readers to deliver inputs for assessment and the target should be for agreements >90% and CV≤10%. IEO and IPMA age readers of anchovy in Division 9a showed a 75.7% agreement (CV=33.0%), which is a reasonable result. However, other exchange workshops are commended in the near future, particularly at IPMA, where there is currently only one experienced reader.

For the Spanish fishery, catch-at-age data (catch numbers-at-age, mean weight-at-age, mean length-at-age) are derived since 1989 from the raised national figures routinely provided by Spain. Both age–length keys and length–weight relationships are compiled on a quarterly basis from monthly market samples.

B.2.2. Weight-at-age of the stock

B.2.2.1. Western component

Mean weights-at-age in this stock component has been estimated from *PELACUS* and *PELAGO* acoustic surveys as well as in the *SAR* and *JUVESAR* autumn surveys (Garrido *et al*., 2018 b).

B.2.2.2. Southern component

Weights-at-age in the stock for the GoC anchovy correspond to yearly estimates calculated as the weighted mean weights-at-age in the catches for the second and third quarters (i.e. throughout the spawning season). Survey-based estimates, especially those ones coming from the *BOCADEVA* DEPM survey are also available, but the datapoints only correspond to 2005, 2008, 2011 and 2017. *ECOCADIZ* acoustic surveys may also provide estimates since 2004 for those years not sampled by the DEPM survey but 2012. However, no direct information is available for the period 1989–2003. The potential of these estimates needs to be explored.

B.2.3. Maturity

Maturity stage assignment criteria were agreed between national institutes involved in the biological study of the species during the Workshop on Small Pelagics (*Sardina pilchardus*, *Engraulis encrasicolus*) maturity stages (WKSPMAT; ICES, 2008).

B.2.3.1. Western component

During 2017, anchovy sampling by IPMA was more intense in the main fishing port of Subdivision 9a CN (Matosinhos), in part as a consequence of the increase of landings in this area. This allowed obtaining data to better defining the anchovy spawning cycle off the western Iberia. According to the cycle of the Condition factor and Gonadosomatic index of anchovies collected during 2017 in Matosinhos (modal size classes, 12–15 cm), the spawning cycle seems to start in March, April, peak in June and end in July/August (Garrido *et al*., 2018b).

Maturity-at-length and maturity-at-age were estimated from the data of the *PELAGO* survey. Maturity-at-age can only be currently estimated from 2008 to present, although a collection of otoliths collected in the acoustic surveys off Portugal is currently being analysed to be able to have age data at least from 1998 to present. Anchovy maturity-at-length is very steep. From data collected by the *PELAGO* survey at subdivisions 9a CN and 9a CS, L50 generally occurs between 10 and 12 cm and is similar between the two subdivisions.

B.2.3.2. Southern component

Previous biological studies based on commercial samples of GoC anchovy (9a S (ES)) indicate that the species' spawning season extends from late winter to early autumn with a peak spawning time for the whole population occurring from June to August (Millán, 1999). Length at first maturity was estimated in that study at 11.09 cm in males and 11.20 cm in females. However, it was evidenced that size at maturity may vary between years, suggesting a high plasticity in the reproductive process in response to environmental changes. The annual length-based ogives have not been updated since those provided by Millán (1999).

Annual maturity-at-age ogives for anchovy in 9a S (ES) for both sexes pooled are routinely provided to ICES (since 1988). They are fishery databased and represent the estimated proportion of mature fish at-age in the total catch during the spawning period (second and third quarters) after raising the ratio of mature-at-age by size class in commercial monthly samples to the monthly catch numbers-at-age by size class (Ramos *et al*., 2018). This approach was adopted because the absence of direct information from surveys during the first 12 years of the available time-series and the discontinuity in this kind of information (i.e. occurrence of some years without survey) during the remaining years. The % mature at age 0 in these annual fishery-based ogives need to be checked since these anchovies may also contribute to the (first-) spawners' population fraction during the third quarter in the year. The potential of the maturity data from the different surveys series surveying the southern component either in spring (*PELAGO*) or summer (*ECOCADIZ* and *BOCADEVA*) also needs to be explored.

B.2.4. Natural mortality

B.2.4.1. Western component

Natural mortality, M, is unknown for this stock component. Cohort tracking of the stock indicator (*PELACUS+PELAGO* acoustic surveys estimates of abundance-at-age) by pooling all cohorts per age indicates that total mortality is -1.76; therefore, natural mortality should be below this value. However, the total mortality estimated by cohort analysis shows high variability and occasionally inconsistent data (see Garrido *et al*., 2018b and ICES, 2018b). Provisionally, the M pattern at-age used for the anchovy in the Bay of Biscay which is 1.2 for age 0, 0.8 for age 1 and 1.2 for older ages could be adopted.

B.2.4.2. Southern component

Previous estimates of natural mortality, M, for this stock component were derived from the development of an Ecopath with Ecosim model for the GoC (Torres *et al*., 2013).

These authors estimated a M=1.498≈1.5 y^{-1} constant for all ages as the result of the combination of a natural mortality caused by predation (M2=1.397 y^{-1}) and by other causes (M0=0.101 y^{-1}).

During the WKPELA 2018, a constant M value was preferred to be selected from classical indirect formulations based on life-history parameters. The R package *FSA* was used to obtain 13 different empirical estimates of M, and a value of M=1.3 was finally adopted (midway between the median and the mean of the available estimates for a maximum age of four years). Currently, it is generally accepted that natural mortality may decrease with age, as far as it is presumed to be particularly greater at the juvenile phase. WKPELA 2018 agreed to adopt for the adult ages of anchovy (ages 1 to 4) the constant natural mortality estimated before (1.3), but for the juveniles (age 0) a greater one, in proportion to the ratio of natural mortality-at-ages 0 and 1 (M_0/M_1) resulting from the application of the Gislason *et al.* (2010) method, that presents natural mortality as a function of the growth parameters. The resulting ratio was M_0/M_1 = 1.7 and, therefore, M_0=1.3*1.7= 2.21. Therefore, the following estimates for M at-age were finally adopted: M0=2.21; M1=1.30; M2+=1.30 (similar at any older age; see ICES, 2018b). Rincón *et al*. (2018b) provide a description of the whole process for deriving the above estimates.

B.3. Surveys

Acoustic and DEPM survey methodologies deployed by the respective national Institutes (IPMA and IEO) are thoroughly described in ICES (2008b, 2009, 2017d). 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 SGSBSA (Study Group on the Estimation of Spawning–stock Biomass of Sardine and Anchovy) and WGACEGG (Working Group on Acoustic and Egg Surveys for Sardine and Anchovy in areas 7, 8 and 9). SISP protocols for both acoustic and egg surveys are still in progress. **Table B.3.1** summarizes the seasonal and regional scope of each of these pelagic surveys.

Table B.3.1. Acoustic and DEPM surveys conducted in Division 9a which provide anchovy population estimates.

<table>
<tr><th>Subdivision</th><th>spring</th><th>summer</th><th>autumn</th></tr>
<tr><td>9a N</td><td>PELACUS (ES)</td><td></td><td></td></tr>
<tr><td>9a C-N</td><td rowspan="3">PELAGO (PT)</td><td></td><td>JUVESAR (PT)</td></tr>
<tr><td>9a C-S</td><td></td><td></td></tr>
<tr><td>9a S</td><td>ECOCADIZ (SP)
BOCADEVA (ES) (DEPM, Triennial)</td><td>ECOCADIZ-RECLUTAS
(SP)</td></tr>
</table>

The survey protocols of the *ARSA* (autumn) groundfish survey series (bottom-trawl survey in Spanish GoC waters) are standardized within ICES International Bottom-trawl Survey Working Group (IBTS). SISP protocols for this survey series are described in ICES (2017e).

All the above mentioned surveys series but *JUVESAR* are currently 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.

B.3.1. DEPM surveys

BOCADEVA survey series (Spanish GoC Anchovy DEPM survey in 9a S)

BOCADEVA is a Spanish survey series conducted by IEO, first with the RV *Cornide de Saavedra* (until 2011) and afterwards with the combined use of RV *Ramón Margalef* (ichthyoplankton samples) and RV *Miguel Oliver* (adult samples during the *ECOCADIZ* acoustic surveys, see below). The surveys series is aimed at the estimation of the GoC anchovy SSB hence the surveyed area is restricted to the GoC shelf waters (20–200 m depth; **Figure B.3.1.1**). The surveys are conducted triennially, in summer, starting in 2005 (five datapoints available, but only four, until 2014, initially considered in the Gadget model presented in WKPELA 2018). Since 2014 is conducted almost synchronously to the *ECOCADIZ* survey (see below). Currently SSB estimates are provided with a CV estimate but without size composition and age structure. SSB estimate in 2014 was estimated with the spawning fraction estimate from the 2011 survey, whereas the SSB estimate in 2017 has been preliminary computed making use of the time-series average spawning fraction estimate. The methods adopted for the processing of anchovy egg and adult data are summarized in **Table B.3.1.1**.

WKPELA 2018 has considered the series, after being initially tested in the Gadget model (see **Sections C.2** and **H.1.5**), too short and little informative. The potential of this survey could be re-evaluated once five or six datapoints are yet available.

Table B.3.1.1. BOCAEVA survey series (GoC Anchovy DEPM survey). Processing and analysis for eggs and adults.

DEPM	Spain (IEO)
EGGS	
Survey area	Gulf of Cadiz (SP and PT) (36º–37.2ºN,-6º–9ºW)
Sampling grid	8 x 3 nm
PairoVET Anchovy eggs staged (11 stages) (adaptation from Moser and Alshtrom, 1985)	All
CUFES egg staged Anchovy (adaptation from Moser and Alshtrom, 1985)	In the lab, all or subsample if more than 100 per sample
Temperature for egg ageing	5 m
Peak spawning hour	daily spawning cycle, lognormal PDF, (equivalent mean=22 h, equivalent sd=2) (Bernal *et al*., 2011)
Egg ageing	Bayesian (Bernal *et al*., 2008)
Egg production	GLM (negative binomial log link)
ADULTS	
Histology: -Embedding material -Stain	 Resin Haematoxilin-Eosin
S estimation	Day 1 and Day 2 POFs
W estimation	Weight of hydrated females corrected by means of a linear regression (from non-hydrated females)
R estimation	The observed weight fraction of the females
F estimation	On hydrated females (without POFs), according to Hunter *et al*., 1985

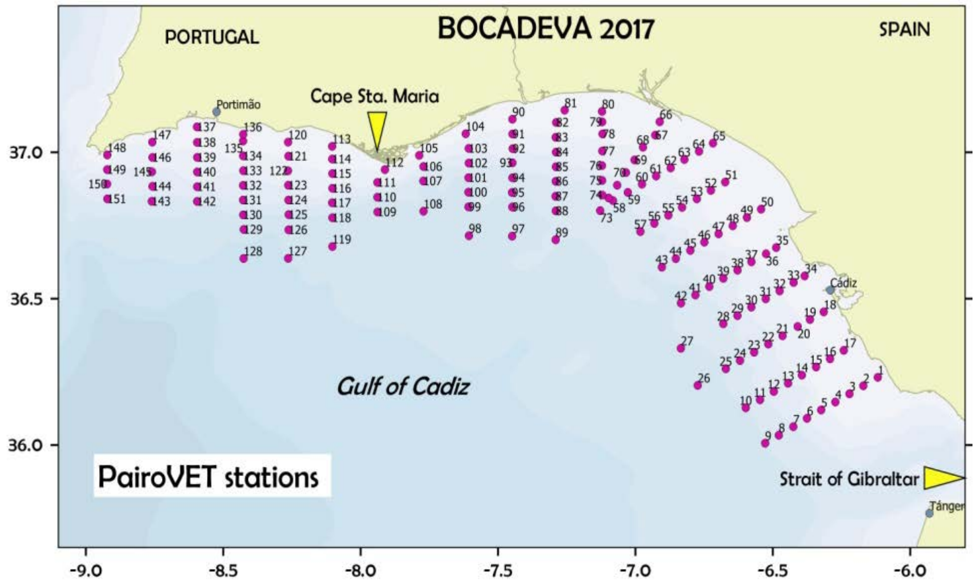

Figure B.3.1.1. ***BOCADEVA*** **GoC anchovy DEPM surveys series. Sampling grid adopted in the surveys based on the** ***BOCADEVA 2017*** **survey. Source: ICES WGACEGG.**

B.3.2. Acoustic surveys

Several acoustic surveys are conducted covering parts of the spatial distribution of each of the stock components of anchovy in Division 9a. During the first semester of the year, both *PELACUS* and *PELAGO* surveys are conducted in spring making a full coverage of the distribution area of the whole stock. In the second semester, there is a full coverage of the southern component with the summer and autumn acoustic surveys series *ECOCADIZ* and *ECOCADIZ-RECLUTAS*, respectively. In the western component, *JUVESAR* survey series is the autumn counterpart of *ECOCADIZ-RECLUTAS*.

All these surveys are coordinated within ICES WGACEGG (ICES, 2017d). Full description on survey design, sampling strategies and data analysis will be found in ICES (2017d). The spring surveys *PELACUS* and *PELAGO* are used for providing a single abundance index by length and 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.

PELAGO survey series (Portuguese Spring acoustic survey in 9a C-N, 9a C-S and 9a S)

The *PELAGO* surveys (Portuguese spring acoustic survey, until 2006 termed as *SAR* spring surveys) are conducted every year since 1999 by IPMA with the RV *Noruega*, surveying the waters of the Portuguese continental shelf and those of the Spanish Gulf of Cadiz (subdivisions 9a C-N, 9a C-S, and 9a S), between 20 and 200 m depth.

Originally it was routinely performed for the acoustic estimation of the sardine abundance in Division 9a off the Portuguese continental shelf and Gulf of Cadiz during March-April (sardine late spawning season). Since 2007 on, spring surveys are being planned as 'pelagic community' surveys. This shift in planning mainly entailed, as compared with previous years, a substantial increase in the number of fishing stations in the Subdivision 9a S, where the species diversity is higher, changing the series its former name by the one of *PELAGO* surveys. Anchovy estimates from these survey series started to be available since March 1999, with gaps in 2000, 2004 and 2012. Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) of the estimated population in numbers and biomass, but age-structured estimates are provided by IPMA only since 2013 on.

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 (**Figure B.3.2.1**). Acoustic data from 38 kHz are 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 echotraces, obtain the length structure of the population, obtain the species proportion and get biologic samples.

The identification of the echotraces 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.

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.

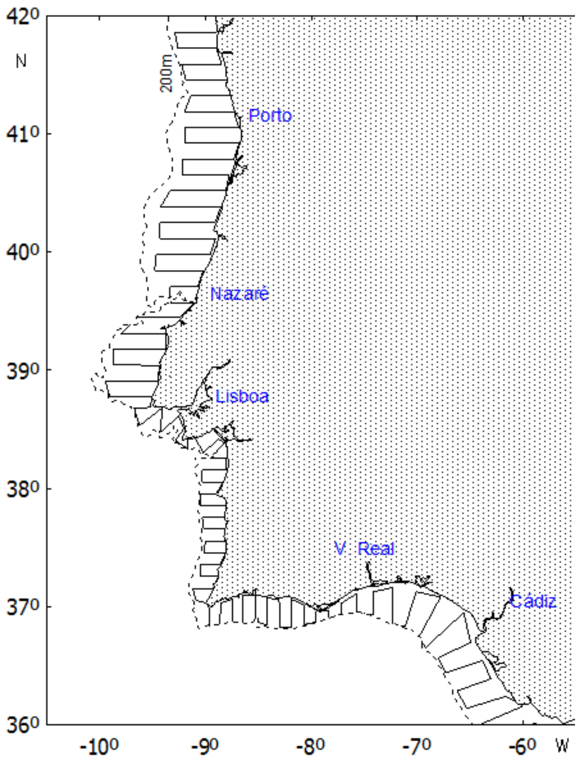

Figure B.3.2.1. Acoustic transects sampled during the *PELAGO* acoustic survey.

PELACUS survey series (Spanish Spring acoustic survey in 8c and 9a N)

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. Since 1998 onwards, 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 exercise between both vessels was conducted in spring 2014 in French waters around the Garonne area. Intra-ship variability of both echointegrated 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 abundance indices obtained from this time-series was needed.

Survey methods and data analysis are described in ICES (2017d). 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 (**Figure B.3.2.2**). Echograms are recorded using several frequencies (18, 38, 70, 120 and 200 kHz), allowing a direct allocation of echotraces 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 groundtruth 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 a 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).

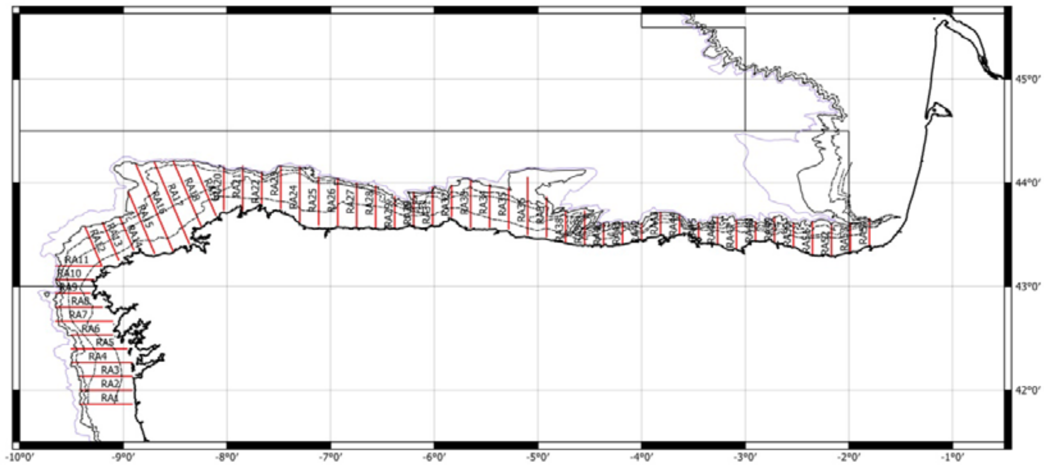

Figure B.3.2.2. Acoustic transects sampled during the *PELACUS* acoustic survey.

This Spanish spring acoustic survey series is the only one that samples yearly the waters off the Subdivision 9a N. This series provides the size and age composition (LFD) of the estimated anchovy population in numbers and biomass in 9a N since 2008.

ECOCADIZ survey series (Spanish Summer acoustic survey in 9a S)

Spanish survey series conducted by IEO, first with the RV *Cornide de Saavedra* (2004–2013) and afterwards with the RV *Miguel Oliver*. This is a pelagic community survey conducted in the GoC shelf waters only (9a S; 20–200 m depth; Figure B.3.2.3). The standard surveyed area comprises the GoC waters, both Portuguese (Algarve) and Spanish ones, with an acoustic sampling grid consisting in a systematic parallel grid of 21 transects equally spaced by 8 nm, normal to the shoreline.

Survey dates were initially planned to be coincident with the GoC anchovy peak spawning (late June–mid-July), but in recent years the survey is usually delayed until late July–mid-August. The series started in 2004, but with gaps in 2005, 2008, 2011 (because available ship time had to be invested in the conduction of the DEPM survey *BOCADEVA*) and 2012 (no survey). Survey methods and data analysis are described in ICES (2017d) and are coincident to those described for the *PELACUS* series. Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) and age structure of the estimated population in numbers and biomass.

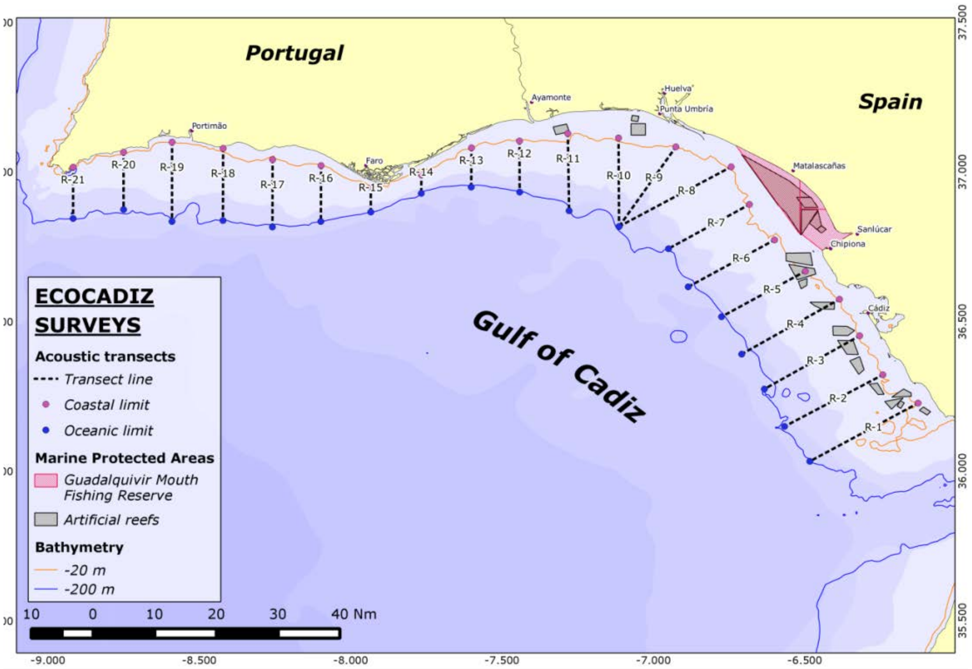

Figure B.3.2.3. Acoustic transects sampled during the *ECOCADIZ* acoustic survey.

SAR (autumn)/JUVESAR survey series (Portuguese Autumn acoustic survey in 9a C-N)

The *SAR* autumn acoustic survey series (aimed to cover the sardine early spawning and recruitment season in the Division 9a, but also covering the anchovy recruitment season) started in 1984 but it hasn't a temporal continuity (e.g. from 1984 to 2008 with gaps in 1988–1991 and 1993–1996) This series re-started again in 2013 onwards as *JUVESAR* survey series. The spatial coverage was not always the same (the *SAR* series covered the same surveyed area as *PELAGO*, and *JUVESAR* now only covering the shallower waters of the Subdivision 9a C-N, from 24 to 60 m depth, the main recruitment area for sardine in Portuguese waters).

The *SAR* autumn series has provided anchovy acoustic estimates from 1998 to 2008, but these estimates are not age-structured. In the case of *JUVESAR* surveys, the scarce presence and abundance of anchovy in the 2013 and 2014 surveys prevented from providing any acoustic estimate for the species. Population estimates are provided without a measure of dispersion.

ECOCADIZ-RECLUTAS survey series (Spanish Autumn acoustic survey in 9a S)

Spanish survey series conducted first by IEO with RV *Emma Bardán* (2012 survey) and afterwards with the RV *Ramón Margalef*. The survey series, although planned as a pelagic community survey, is aimed at the acoustic estimation of both GoC anchovy and sardine juveniles and restricted to the Subdivision 9a S (20–200 m depth). The surveys series, conducted during the second fortnight of October, is still a very short series: started in 2012 (only Spanish waters sampled) and continued in 2014. A serious breakdown in the RV's propeller system prevented from deriving an acoustic estimate from the 2017 survey. Surveyed area, sampling and data analysis methods are the same than the ones described above for its summer counterpart *ECOCADIZ*. Population estimates are provided without a measure of dispersion. This series provides the size composition (LFD) and age structure of the estimated population in numbers and biomass. WKPELA 2018 stated that *ECOCADIZ-RECLUTAS* series could be used in future as a good indicator of anchovy recruitment (which is the basis of the fishery) in 9a South once a longer time-series is available. As described before, there is no estimate in 2017, and a time-series with at least six observations will not be available until 2020, when the suitability of this series for its inclusion in the assessment could be re-evaluated in a future benchmark.

B.3.3. Other surveys

ARSA (autumn) bottom-trawl survey series (Spanish Autumn bottom-trawl survey in the Spanish waters of the Goc, 9a S)

ARSA autumn series is a Spanish survey series conducted by IEO first with the RV *Cornide de Saavedra* (1997–2013) and afterwards with the RV *Miguel Oliver*. This is the IBTS survey in the GoC. The surveyed area is restricted to the Spanish GoC, between 15 and 800 m depth (separated in five depth strata: 15–30, 31–100, 101–200, 201–500 and 501–800 m; **Figure B.3.3.1**). This series has also a spring (March) counterpart.

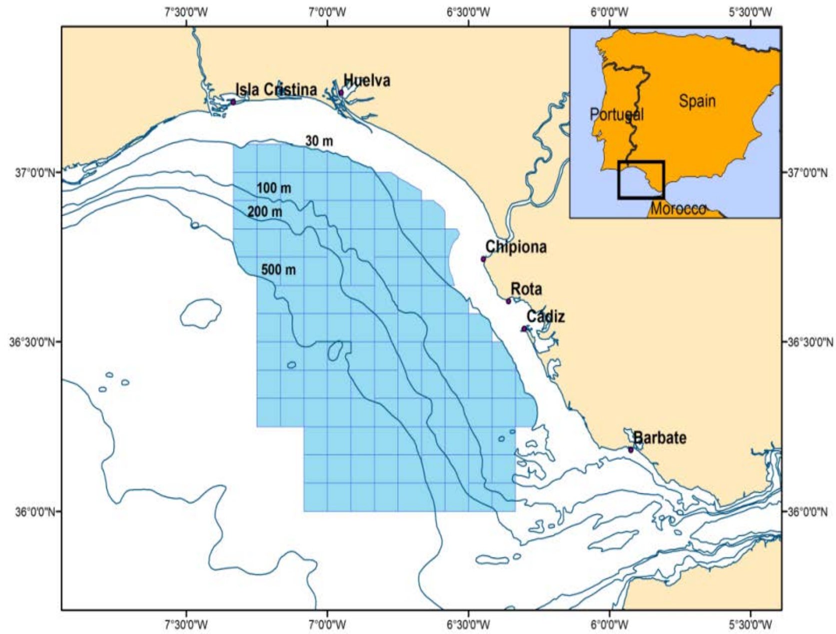

Figure B.3.3.1. ***ARSA*** **autumn bottom-trawl survey. Depth strata and sampling grid adopted in the surveys. Only Spanish waters are surveyed by the survey.**

The *ARSA* autumn series started in 1997. GoC anchovy estimates are provided by this series since 1997. The series provide relative indices (cpue in number and g/trawling hour) and absolute indices (after applying the swept-area method). Both types of indices are provided with estimates of bias. Size-based estimates of the relative abundance indices are routinely computed. LFDs for the absolute indices are also available. Although they have not been considered in the assessment model, age-structured estimates from this survey series have also been computed by applying the corresponding Spanish quarterly commercial ALKs. WKPELA 2018 noted that some additional studies are still needed to measure the consistency of this survey series and its suitability for assessment purposes.

B.3.4. Survey data used

At present, the surveys used in the assessment of the western component of the anchovy stock in 9a are the spring acoustic surveys *PELACUS* and *PELAGO* (for subdivisions 9a N, 9a C-N and 9a C-S), which jointly provide a full coverage of this stock component. For the southern component, the selected surveys to be included in the analytical assessment model (Gadget model) are *PELAGO* and *ECOCADIZ*.

B.4. Commercial cpue

According to literature, cpue indices have been considered as not reliable indicators of abundance for small pelagic fish (Ulltang, 1980; Csirke, 1988; Pitcher, 1995; Mackinson *et al*., 1997).

B.4.1. Western component

Cpue indices are not considered for this stock component.

B.4.2. Southern component

At present, the series of commercial cpue indices is only used for interpreting the Spanish purse-seine fleets' dynamics in Subdivision 9a S. Thus, data on annual values of nominal effort (fishing trips targeting on anchovy) and cpue by fleet type have routinely been provided to ICES. The series of effective effort and cpue from all of the Spanish fleets exploiting the Gulf of Cadiz anchovy were provided for the first time to the WGMHSA in 2004. For such a purpose, vessels from single-purpose fleets were additionally differentiated according to their tonnage in heavy- (≥30 GRT) and light- (<30 GRT) tonnage vessels, rendering a total of eleven fleet types.

The standardisation procedure was performed in the last years by fitting quarterly log-transformed cpues from fleet types composing the fishery to a GLM (Robson, 1966; Gavaris, 1980) which only included the effects of quarter and fleet type (without any interaction), (ICES, 2007 a). Since 2008, the GLM fitting is performed with the following modifications to the original version: (a) the effect of missing values in the nominal cpue data were smoothed by adding a constant value to data before their log-transformation (ICES, 2008 b). In this case, this constant was computed as the 10% of the average value for the whole nominal cpue series resulting in log(cpue-adjusted) data. (b) the model includes year, quarter, fleet type and first order interaction effects. Reference fleet (métier or fleet type), year and season used in the standardisation were the Barbate's single-purpose high-tonnage fleet, the first year in the series, 1988, and the first quarter in the year, respectively. The updated series of standardised effort and cpue from all of the fleets exploiting the fishery is provided to the WG each year. Annual and half-year standardised cpue series for the whole fleet are computed from the quotient between the sum of raw quarterly catches and that of standardised quarterly efforts within each of the respective time periods (**Figure B.4.2.1**).

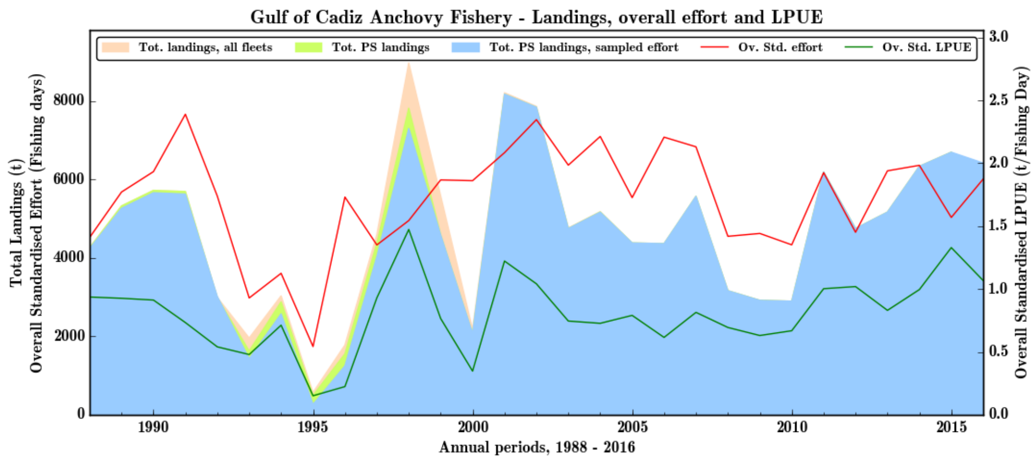

Figure B.4.2.1. Anchovy in Division 9a. Subdivision 9a South. Spanish purse-seine fishery (métier PS_SPF_0_0_0). Trends in Gulf of Cadiz anchovy annual landings, and purse-seine fleets' standardised overall effort and lpue (1988–2016).

C. Assessment: data and method

C.1. Western component

Input data for the assessment

Anchovy in 9a West consist mostly of 1 and 2 year-olds on both the stock component and the catches. Moreover, there is no time-series of regular information of the composition by length and age of the catches, mostly because this stock component (and catches) suffers strong year-to-year changes in abundance. For these reasons, this stock component was considered by WKPELA 2018 as a category 3 stock (ICES, 2018b).

An approach for an in-year advice for both stock components, based on survey biomass estimates and sustainable harvest rates estimated from a yield-per-recruit analysis was presented to WKPELA 2018 (Uriarte *et al.*, 2018; ICES, 2018b; see **Section H.1.3.5**). However, WKPELA 2018 did not considered this approach sufficiently tested and divergent from the standard ICES advices for DLS (ICES, 2012b), and from the ones being used for other short-lived stocks (e.g. sprat).

Accordingly, a data exploration using an interim procedure based on an in-year trend-based catch advice was undertaken during the benchmark workshop (ICES, 2018b). According to standard ICES guidelines for short-lived DLS, the method 3.2 (ICES, 2012b) and variations of this method were explored (Uriarte *et al.*, 2018; Garrido *et al.*, 2018b; ICES, 2018b).

The anchovy biomass indicator (I) for the Western component is computed in this interim procedure as the sum of *PELACUS* (9a N) and *PELAGO* (9a C-N and 9a C-S) acoustic estimates. Total catches from these western subdivisions are also used. Variations of the 3.2 method using survey trends based on 4, 3, and 2 previous years (I_i) comparing with the current year (I_y) were tested, to provide in-year catch advice (C_y). Due to the large variability of anchovy abundance in the west from year to year, the trend that best corresponds to changes in stock biomass is the one comparing the least amount of years, namely the current with the two previous years (see below).

Choice of the stock assessment model

In the absence of a DLS approach for short-lived species and for in-year advice, WKPELA 2018 suggested an interim procedure (subsequently revised by WGHANSA 2018 and accepted by ADGHANSA 2018) for the anchovy in the Western area of Division 9a:

Apply a trend-based procedure by analogy with the current method 3.2 (ICES, 2012b), (similarly to the approach used for other short-lived species such as sprat in 27.3a and 27.7de.) according to the following formula:

$$C_y = \begin{cases} 0.8C_{y-1} & if \ \dfrac{I_y}{(I_{y-1}+I_{y-2})/2} < 0.8 \\ C_{y-1}\dfrac{I_y}{(I_{y-1}+I_{y-2})/2} & if \ 0.8 \le \dfrac{I_y}{(I_{y-1}+I_{y-2})/2} \le 1.2 \\ 1.2C_{y-1} & if \ \dfrac{I_y}{(I_{y-1}+I_{y-2})/2} > 1.2 \end{cases} ,$$

where C_y and I_y represent the catch advice and the biomass indicator corresponding to year y, respectively (for the first time of the assessment, C_{y-1} represents catches in the previous year) . Note that the first and third cases correspond to the application of an uncertainty cap of 0.8 and 1.2, respectively (20% uncertainty cap).

Regarding the application of this uncertainty cap, it is considered that it might not be appropriate to short-lived species. Therefore, this procedure should be evaluated for this kind of species in an appropriate forum.

Model used of basis of the advice

As described above, the timing of the advice of anchovy in 9a West can be made available in-year (during the assessment WG in late June in year y), after the *PELACUS* (April) and *PELAGO* (May–June) surveys estimates are available. Therefore, the trend-based assessment includes acoustic data up to year y. The catch advice is framed in a management calendar set from 1st July (y) to the following 30th June ($y+1$), instead of calendar years.

As starting catch for C_{y-1} , two options for the in-year advice in July 2018 may be considered: either the catches happening in 2017 (for a management calendar based on calendar years) or those catches landed during the period July 2017 to June 2018 (for an in-year advice based on a management calendar lasting from July in the year y to June in the year $y+1$). This last option is the adopted one and it implies to have an approximate value of the catches for the first half in 2018, since the exact total number may not be available at the time the WGHANSA meets (last week of June). Since then onwards, the catch advice of the former management period will be used as the starting catch. WGHANSA experts consider as the best option the second one because it does not require update advice. Furthermore, under the first option (management calendar based on calendar years) catch options from January to June in the year y should be decided by ICES and managers (and no particular guidelines have been produced in WKPELA; ICES, 2018b).

Assessment model configuration

Both configuration and possible options of the interim procedure for the assessment of the 9a West anchovy have been described above.

C.2. Southern component

Input data for the assessment

A single-species Gadget (*Globally applicable Area Disaggregated General Ecosystem Toolbox*; Begley, 2004; Begley and Howell, 2004) integrated assessment model, fitted to fishery, biology and surveys data from the anchovy southern stock component, was evaluated in WKPELA 2018 (ICES, 2018b; Rincón *et al*., 2018b). A full description of the software used, input data types and characteristics and model options is shown in **Section H.1.5**. The model fit, although acceptable, showed some instability (e.g. occurrence of a certain retrospective pattern), and was sensible to the selection of the natural mortality estimate. Furthermore, the resulting absolute levels of biomass and catchability (quite high for both acoustic survey series considered so far in the model: *PELAGO* and *ECOCADIZ*) did not seem to be credible. Accordingly, WKPELA 2018 considered for the time being this stock component as a category 3 stock, and agreed that the assessment is done using a category 3 assessment, in exactly the same manner as previously described for the Western stock component (i.e. an in-year variation of the method 3.2 for category 3 stocks; see **Section C.1** and ICES, 2018b).

The Gadget assessment, while not reaching the full analytical stage (i.e. category 1 stock), provides trends for biomass, recruitment and fishing pressure. In order to take advantage of this improvement as compared to the former situation (see **Section H**), the trend-based assessment makes use of the biomass estimates from the Gadget model, as indicative of trends only, instead of the direct survey estimates. Total catches from the international fishery in the Subdivision 9a S are also used.

Choice of the stock assessment method

In the absence of a DLS approach for short-lived species and for an in-year advice, WKPELA 2018 suggested to apply for the assessment of the anchovy southern stock component the same interim procedure for the assessment of the anchovy in the western area of Division 9a (see **Section C.1**), including the application of a 20% uncertainty cap, but also bearing in mind the same considerations on this issue specified in **Section C.1**. In this particular case of the southern stock component, the stock biomass indices (I) used in the equation are the resulting biomass estimates from the Gadget assessment instead the direct survey estimates, as it is defined for the Western stock component.

Model used of basis of the advice

Timing for the advice of the southern component could also be produced in the annual assessment WG in late June, after the *PELAGO* survey (May–June), for an in-year advice, following the same interim procedure and management calendar adopted for the assessment and provision of advice of the western anchovy. In this case, the Gadget model (which provides the estimates of the biomass indicator) is fitted to the data available at the timing of the advice (the input of the *ECOCADIZ* survey is omitted, as it will take place afterwards, in late July). Therefore, the trend-based assessment for this stock component implicitly includes acoustic data up to the timing of the advice in the year y. The advice will serve to set an advice (C_y) from July in the year y to June next year until a new assessment is made in the same way. The Gadget assessment would always incorporate *ECOCADIZ* survey estimates (as agreed in the benchmark), but only up to year y-1. A comparison of the model outputs and retrospective analyses for the model base case and its in-year version performed during WKPELA 2018 showed no substantial differences between these two model settings (ICES, 2018b).

The abovementioned approach aims to partially overcome the unknown levels of recruitment when the assessment and advice is produced (within a management calendar based on calendar years) either in July or November for the following year. This advice would require assuming a certain level of recruitment occurring in January, but at least the first half of the management year (July–December in the year *y*) will be informed on the actual level of recruits at age 1 recorded by the in-year survey (*PELACUS +PELAGO* acoustic surveys for the western component, *PELAGO* survey for the southern component), which sustains the bulk of catches in that period. These surveys estimates become available in late May–early June, shortly before WGHANSA meeting in June.

This option does not require update advice, and allows having advice for anchovy in 9a West and South at the same time of the year (in late June–early July, after the WGHANSA meeting) for TACs covering the management calendar (July–June). This management procedure would be revised in future once recruitment surveys (*JUVESAR* in the West, *ECOCADIZ-RECLUTAS* in the South) would be validated and incorporated in the assessment and advice.

As starting catch for C_{y-1} , two options for the in-year advice in July 2018 may be considered: either the catches happening in 2017 (for a management calendar based on calendar years) or those catches landed during the period July 2017 to June 2018 (for an in-year advice based on a management calendar lasting from July in the year *y* to June in the year *y+1*). This last option is the adopted one and it implies to have an approximate value of the catches for the first half in 2018, since the exact total number may not be available at the time the WGHANSA meets (last week of June). Since then onwards, the catch advice of the former management period will be used as the starting catch. This last option also implies that the catch advice would be calculated using the biomass estimated by the Gadget model at the end of June, where there are no individuals of age 0, (then these abundance estimates correspond to individuals of age 1+). Due to some inconsistencies in the maturity ogives not noticed during WKPELA 2018, we assume that all individuals with age 1 or higher (B1+), are mature, i.e. these abundance estimates result equivalent to spawning-stock biomass estimates.

Assessment model configuration

Both configuration and possible options of the interim procedure for the assessment of the 9a South anchovy have been described above. Gadget model configuration is described in **Section H.1.5** and in Rincón *et al.* (2018b).

D. Short-term projection

D.1. Western component

No short-term projection has been defined for this stock component.

D.2. Southern component

No short-term projection has been defined for this stock component.

E. Medium-term projections

No medium-term projections are applied to this fishery for the provision of advice by ICES.

F. Long-term projections

No long-term projections are applied to this fishery for the provision of advice by ICES.

G. Biological reference points

No reference points for the anchovy stock in Division 9a has been previously defined.

G.1. Western component

SPICT (Production model in Continuous Time; Pedersen and Berg, 2017) was explored in WKPELA 2018 to assess the 9.a-west anchovy and derive proxy MSY reference points (Garrido *et al.*, 2018b). However, in all model runs, the parameters had large confidence intervals and the results were not accepted (see **Section H.1.4**).

Harvest Rate limit and precautionary reference points (HR_lim; HR(PA); HR(PATarget)) have been estimated within the procedures proposed for an in-year advice for anchovy in 9a based on survey biomass estimates and sustainable harvest rates from Yield-per-recruit analysis (Uriarte *et al.*, 2018). However, this approach was neither accepted by WKPELA 2018 (ICES, 2018b) because it was not sufficiently tested and diverged from the standard ICES advices for DLS (ICES, 2012b), and from the ones being used for other stocks of short-lived species. Instead, WKPELA 2018 has suggested an interim procedure for the assessment of this stock component based on a trend-based procedure, which does not contemplate any reference point (see **Section C.1** and ICES, 2018b). Therefore, at present there are no reference points defined for this component.

G.2. Southern component

The results from an exploratory exercise of deterministic estimation of biological reference points (BRP) for this stock component were presented in WKPELA 2018 meeting (ICES, 2018b). The computation of such BRPs was based on data from the Gadget assessment presented in that meeting under the assumption that this stock component could be category 1 or 2 (see also **Section C.2**). The methodology used followed the framework proposed by ICES (2017f) guidelines for fisheries management reference points for category 1 and 2 stocks and by ICES WKMSYREF5 (ICES, 2017g).

According to the above ICES guidelines and the SSB-R plot characteristics, this stock component can be classified as a "stock type 5" (i.e. stocks showing no evidence of impaired recruitment or with no clear relation between stock and recruitment (no apparent SSB–R signal)). According to this classification, B_{lim} estimation is possible according to the standard method and it is assumed to be equal to B_{loss} (B_{lim}=B_{loss}).

ICES recommends to calculate B_{pa} as follows:

$$B_{pa} = B_{lim}e^{1.645\sigma},$$

where σ is the estimated standard deviation of ln(SSB) in the last year of the assessment, accounting for the uncertainty in SSB. If σ is unknown and for short-living species, as it is in our case, it can be assumed that σ = 0.30 (ICES, 2017g), then,

$$B_{pa} = B_{lim}e^{1.645\times0.3} = 1.64B_{lim}$$

Note that this formulation corresponds to assume Bpa as the upper 95% of the distribution of the estimated SSB if the true SSB equals B_{lim} based on a terminal SSB coefficient of variation equal to 0.3.

F PA reference points didn't need to be defined since ICES does not use F reference points to determine exploitation status for short-lived species.

WKPELA 2018 has suggested for the assessment of this stock component (categorized as a Category 3 stock) the same interim procedure adopted for the Western stock component, which does not contemplate any reference point. Nevertheless, an exploratory assessment with SPICT aimed to provide proxy reference points for Category 3 stocks (ICES, 2016) was also attempted in the interim between WKPELA 2018 and WGHANSA 2018 meetings, but the model runs did not converge. Length-Based Indicators (LBI) were also previously computed for this stock component in 2013 (ICES, 2013), but their appropriateness for short-lived species was questioned by the WG (see **Section H.1.2**). At this point, WGHANSA 2018 (and ADGHANSA 2018) considers that the Gadget-based biomass reference points are still useful to establish the stock (component) and exploitation status of the southern anchovy, although they should be used as relative values (in relation to the SSB historical average).

H. Other issues

H.1. Historical overview of previous assessment methods

H.1.1. *Ad hoc* seasonal separable VPA model

Data availability and some fishery (recent catch trajectories) and biological evidences were the basis for a previous data exploration of anchovy catch-at-age data in Subdivision 9a South (Algarve and Gulf of Cadiz) until 2009 by applying an *ad hoc* seasonal (half-year) separable model implemented and run on a spreadsheet (Ramos *et al*., 2001; ICES, 2002). Nevertheless, the exploratory assessments performed with this model were not recommended as a basis for predictions or advice due to they did not provide any reliable information about the true levels of the stock, F and Catch/SSB ratios since the assessment was not properly scaled. For the above reasons since 2009, it was preferred not to perform any exploratory assessment with this model. More details on the model settings and assumptions and its performance are described in ICES (2008b).

H.1.2. Assessment based on life-history traits (LHTs) and Exploitation characteristics

Upon request from the Workshop on the Development of Assessments based on life-history traits and exploitation characteristics (WKLIFE; ICES, 2012c), a first compilation and further exploration of available data on life-history traits (LHTs) of anchovy in Division 9a was presented in the 2013 WGHANSA meeting (ICES, 2013). Length-based reference points considered were: length (L_{mat}) at 50% maturity, von Bertalanffy growth parameters (L_{inf} ($L\infty$), $K,t0$), mean length at first capture (Lc, determined as the length at half of the maximum frequency in the ascending part of the curve), length where growth rate in weight is maximum ($Lopt$, where $Lopt = 2/3$ of $Linf$ ($L\infty$)), and the theoretical length resulting from fishing with F = M ($L(F=M)$, where $L(F=M) = (3 * Lc + Linf)/4$). With weighted mean length in the catch (*Lmean*) as indicator (computed as the mean of fish larger than *Lc*), several of these population characteristics could be used as reference points to infer relative exploitation and relative stock status.

This exploratory analysis was focused in anchovy LHTs from the Subdivision 9a South (Spanish waters) because of the greater data availability. The resulting estimates seemed to suggest that the stock is supporting in its recent history a reasonable exploitation with L_{mean} above $L_{(F=M)}$ and very close to L_{opt} and L_c=L_{mat}. Nevertheless, WGHANSA members questioned the validity or appropriateness of these reference points for short-lived species like anchovy (with stocks and catches supported mainly by only age group and a fishery operating around spawning time). For the above reasons this exploratory analysis has not been updated since then.

H.1.3. Trend–based qualitative assessment: stock size and harvest rate indicators

H.1.3.1. Trends of stock biomass size indicators

The anchovy stock in Division 9a (ane.27.9a) has not been analytically assessed until 2018. ICES considered this stock as an ICES Stock Data Category 3, and it was qualitatively assessed through a survey biomass trend-based assessment without catch advice (ICES, 2017a). No catch advice could be given for the next year to the assessment because of a lack of available data for the year classes that will constitute the bulk of the biomass and catches.

The provision of advice from 2009 to 2014 for the whole Division 9a has been restricted to Subdivision 9a south, which was the only area where a more persistent and stable population and fishery existed, and where sufficient information from age and length composition of landings could be provided. The advice relied in an update of the qualitative assessment carried out in 2008 (ICES, 2008b) and accepted by the ICES Review Groups (RG) of the 2008 and 2009 ICES WGANC (2008 and 2009 RGANC). This qualitative assessment was based on the joint analysis of trends showed by the available data for the Subdivision 9.a South, both fishery-dependent and fishery-independent information (*i.e.* landings, fishing effort, cpue, survey estimates).

The stock size indicator for the Subdivision 9a was estimated as the average of the annual estimates provided by each of the spring–summer surveys conducted in the subdivision (*PELAGO*, *ECOCADIZ*, *BOCADEVA*). The rationale of this approach was based on the uncertainties in the anchovy acoustic assessment in the Spanish waters area and the gaps occurring in the *ECOCADIZ* series up to 2012, which led to consider this averaging procedure under the assumption of equal catchabilities between surveys. Notwithstanding the above, the adoption of this approach evidences some problems: first, in the moment of the provision of advice by ICES (late June), summer surveys estimates are not yet available. Therefore, the resulting indicator for the southern component in the assessment year is incomplete, since it is only based on the *PELAGO* spring estimate. The value for that year is then re-computed in the next year meeting with all the estimates available, which results in a not a very consistent approach. Second, there are serious doubts about the suitability of this computation method because the datapoints through the time-series are estimated with a different number of surveys depending on their availability (recall that *BOCADEVA* is triennially conducted). In fact, the ICES ADGANE9a in October 2016 was concerned about this way of combining survey biomass estimates to reach a total estimate of biomass for Division 9a and recommended to WGHANSA to look at methods to combine survey indices for each stock component.

Since 2015, stock size biomass indicators for the western (subdivisions 9a N, 9a CN and 9a CS) and southern (Subdivision 9a S) components of the stock have been computed to illustrate biomass trends at a regional scale. For the western component, this indicator is estimated as the sum of spring acoustic estimates from *PELACUS* and *PELAGO* spring acoustic surveys.

H.1.3.2. Assessment of potential fishery Harvest Rates (HR) on anchovy in Subdivision 9.a South

A range of a likely potential Harvest Rates (HR) applied for the fishery on the anchovy in Subdivision 9a South was directly tried since 2009 through the estimation of the quotient between total Catch (tons) and the stock size indicator for a range of potential catchabilities of the surveys. Given the rather consistent levels of biomass estimates provided by the acoustic and DEPM surveys applied in this area, the HR evaluation assumed equal catchability for all surveys, something coherent with the results from the assessment of the Bay of Biscay anchovy, which assumes q=1 to the DEPM and estimates q=1.15 (approximately) for the acoustic. In addition, a sensitivity analysis of the HRs for a range of catchabilities from 0.6 to 1.6 was also explored.

H.1.3.3. Yield-per-recruit analysis and Reference Point on Harvest Rates

Although the current fishing pattern is uncertain, the matrix of catches-at-age allow to estimate the selectivities-at-age (relative fishing mortalities-at-age), which for an assumed natural mortality (M=1.2) would equal the relative catches-at-age (in percentages). For a given selectivity-at-age, the Yield-per-recruits can be computed straightforward. This section contains the sensitivity analysis of a Yield-per-recruit analysis in terms of reference points for fishing mortality and Harvest Rates:

In 2012, two vectors of relative catches-at-age were defined, generated from the catch statistics: a first vector corresponded to the average age composition in the period 1999–2011. A second vector corresponded to the catches in the earlier period and 2011 (years 1996, 1997, 1998 and 2011) when catches-at-age 0 were more abundant. These two vectors are summarised in the text table below:

Mean catches-at-age	Age 0	Age 1	Age 2	Age 3	Total
Mean 1999–2011	87.078	414.957	15.022	0.252	517.309
Percentage-at-age	16.8	80.2	2.9	0.05	100

Mean catches-at-age	Age 0	Age 1	Age 2	Age 3	Total
Mean 1996, 1997, 1998 and 2011	374.929	479.572	19.244	0.000	873.745
Percentage-at-age	42.9	54.9	2.2	0.0	100

As the addition of the 2012–2016 catches would generate mean catches-at-age for the period 1999–2016 almost equal to the period 1999–2011 (see table below), and it is somewhere in the middle between the one typical of the period 1999–2011 and that of the period 1996, 1997, 1998 and 2011.

Mean catches-at-age	Age 0	Age 1	Age 2	Age 3	Total
Mean 1999–2016	94.197	431.875	13.850	0.182	540.104
Percentage-at-age	17.6	79.9	2.5	0.0	100

Then the WGHANSA decided not to remake the calculations associated to the sensitivity analysis, which follows (as done in 2012). And as such the two catch-at-age vectors have remained constant and correspond to the two types of catches, one for the period 1999–2011 and the other for the period 1996, 1997, 1998 and 2011 (when ages 0 were more abundant in catches).

Mean weights-at-age in the catches for the same period were used for both the catches and the population. Maturity was assumed to be knife-edge like, full maturity and reproductive capacity-at-age 1 (as estimated to happen here at least during the recent years and consistent with the biology of the anchovy in the Bay of Biscay as well).

As the selectivities required to reproduce the relative catches-at-age can slightly change according to the actual level of fishing mortality (unknown), selectivities were fitted for a vector of potential F values at age 1 (the age of reference) going from 0.2 to 1.4 in steps of 0.2. For each fitted selectivity-at-age a Yield-per-recruit analysis was made in terms of % of Spawning Biomass per Recruit (50%, 40%, 35%SBR) for different levels of F multipliers and corresponding Harvest Rates (HR) (the quotient between catches in tonnes and stock size indicators). Spawning and surveying times were set to occur in the middle of the year. For the acoustic *ECOCADIZ* and DEPM *BOCADEVA* surveys, this is correct, as they are made in June–July, though acoustic *PELAGO* survey is made in April.

Sensitivity to the vector of natural mortality was not made as it was assumed to be constant across ages at an annual rate of 1.2, which given the extremely few ages 2 or older seemed to be plausible value for this population.

The Y/R assessment was made with an Excel spreadsheet. The selectivities at different F at age 1 levels were fitted with the Solver function. The subsequent associated Y/R analysis is run with visual Basic macro in Excel.

Uriarte *et al.* (2018) presents an updating of this procedure including in the analysis a third vector of relative catches-at-age, with catches-at-age 0 of about 5%, a percentage quite smaller than the observed.

H.1.3.4. In year advice for anchovy in 9a West based on survey biomass estimates and sustainable harvest rates from Yield-per-recruit analysis

Given that there is no standard methodology for in-year advice of short-lived species with high interannual variability of abundance, mostly dependent of the recruitment strength, Uriarte *et al*. (2018) suggested an approach for provision of in-year advice for the Western population of Anchovy in Division 9a to WKPELA 2018.

This approach follows from previous ICES practices for this anchovy, whereby a Yield/recruit analysis was accepted as a basis to judge if past harvest rates were sustainable or not, at least since 2012. The proposals presented to WKPELA aimed to overcome part of the limitations noted to this approach in previous years by ACOM, particularly regarding the little testing of alternative selection pattern at-ages in the fishery, and that of not incorporating different growth patterns (others than those of the anchovy in 9a South).

The Uriarte proposal relies on the definition of sustainable harvest rates relative to the biomass estimated by the surveys covering the Western population of Anchovy in Division 9a (*PELACUS* and *PELAGO*, carried out in April, although the estimates become available in May). Sustainable target harvest was chosen as that leading to 50% of the spawning biomass of the unexploited population (50%SBR), as obtained from a general Yield-per-recruit analysis. For the Y/R analysis, an ample range of fishery patterns (selectivity-at-age) and a plausible range of Natural mortality-at-age, given the growth pattern of the selected species (the anchovy in the two regions of Division 9a, western and southern regions) were tested, as well as considerations about the likely bias (or Catchability Q) of the surveys.

For the base case of Natural mortality, i.e. assuming M similar to that for the Bay of Biscay, and for a selectivity-at-age in the fishery flat for all adult age classes (i.e. ages 1+) and for a selectivity-at-age 0 equal to 0.05, Uriarte's procedures computed a precautionary and risk averse sustainable Harvest Rate-based Reference Point accounting for survey uncertainty. However, WKPELA 2018 did not considered this approach sufficiently tested and divergent from the standard ICES advices for DLS (ICES, 2012), and from the ones being used for other short-lived stocks like sprat.

H.1.4. Exploratory assessment of the Western stock component with SPICT

SPICT (Production model in Continuous Time; Pedersen and Berg, 2017) was explored to assess the 9.a-west anchovy and derive proxy MSY reference points (Garrido *et al*., 2018b). SPICT is one of the tools recommended to assess and provide proxy reference points for Category 3 stocks (ICES, 2016). Two spring acoustic surveys were considered reliable indicators of anchovy biomass in the 9a West (*PELACUS* and *PELAGO*). Model runs were carried out with the annual catches (1989–2016) and spring acoustic survey biomass indices (1999–2016). The model was fit using the R script SPICT available from https://github.com/mawp/spict.

The runs carried out in this work lead to converging models in most cases. Compared to the Schaeffer type models, the Fox models had better behaved residuals, complying with normality and independence assumptions. Moreover, parameter estimates were slightly more precise and the estimates of survey catchability and biomass as well as derived quantities such as B_{MSY} looked more realistic. In runs 5 and 6, the models showed a good fit to the data, and there were no violations of assumptions. However, in all model runs the parameters had large confidence intervals. Although some uncertainty is to be expected given the typical large fluctuations of this stock, WKPELA 2018 considered that these large confidence intervals were a consequence of the short time-series. Further exploration is needed trying to improve the model and try to use it to provide reliable assessment of anchovy in the 9a West. This includes fixing additional parameters (e.g. B/K, acoustic survey observation error), which might improve confidence limits. In addition, seasonal catch data and the use of autumn surveys (demersal or acoustic) might be worth exploring in future. Finally, the use of an environmental indicator (e.g. satellite-derived Chla data) can be explored in this model.

H.1.5. Gadget assessment model for the 9a South anchovy

A single-species Gadget (Globally applicable Area Disaggregated General Ecosystem Toolbox; Begley, 2004; Begley and Howell, 2004) integrated assessment model, fitted to fishery, biology and surveys data from the anchovy southern stock component, was evaluated in WKPELA 2018 (ICES, 2018b; Rincón *et al*., 2018b). The occurrence of a certain retrospective pattern in the model fit, its sensitivity to the selection of the natural mortality estimate and, especially, the resulting quite high surveys catchabilities, were factors that WKPELA 2018 considered sufficient to reject, for the time being, this assessment as a category 1 and categorized this stock component as category 3. Nevertheless, WKPELA 2018 agreed that the Gadget assessment is used to provide biomass estimates to be used as input in the category 3 method used for providing in-year advice. The main features of this assessment (model structure, input data, settings, assumptions) are described in the following sections taken from Rincón *et al*. (2018b).

H.1.5.1. Model description

Gadget is an age–length-structured model that integrates different sources of information in order to produce a diagnosis of the stock dynamics. It works making forward simulations and minimizing an objective (negative log-likelihood) function that measures the difference between the model and data, the discrepancy is presented as a likelihood score for each time period and model component.

The general Gadget model description and all the options available can be found in Gadget manual (Begley, 2004) and some specific examples can be found in Taylor *et al*. (2007); Elvarsson *et al*. (2014) and WKICEMSE assessment for Ling (ICES, 2017h). The latest was used as a guide for this document. A formal mathematical description is given in Frøysa *et al*. (2002).

The Gadget model implementation consists in three parts, a simulation of biological dynamics of the population (simulation model), a fitting of the model to observed data using a weighted log-likelihood function (observation model) and the optimization of the parameters using different iterative algorithms.

A list of the symbols used and a graph with the Gadget model structure are presented in **Table H.1.5.1** and a prezi canvas available at

http://prezi.com/j8rinhq5kstg/?utm_campaign=shareandutm_medium=copy respectively.

H.1.5.1.1. Simulation model

The base case model consists of one stock component of anchovy (*Engraulis encrasicolus*) in the ICES Subdivision, 9.a South-Atlantic Iberian waters, Gulf of Cádiz. Gadget works by keeping track of the number of individuals, $N_{a,l,y,t}$, at age $a = 0,\ldots,3$, at length $l = 3, 3.5, 4, 4.5,\ldots, 22$, at year $y = 1989,\ldots, 2016$, and each year divided into quarters $t = 1,\ldots, 4$:. The last time-step of a year involves increasing the age by one year, except for the last age group, which its age remains unchanged and the age group next to is added to it, like a 'plus group' including all ages from the oldest age onwards (Taylor *et al*., 2007).

Growth

The growth function is a simplified version of the von Bertalanffy growth equation, defined in Begley (2004) as the LengthVBSimple Growth Function (*lengthvbsimple*). Length increase for each length group of the stock is given by the equation below (equation 1):

$$\Delta l = (l_\infty - l)(1 - e^{k\Delta t}),$$

where Δt is the length of the time-step, l_∞ = 19 cm (fixed) is the terminal length and k is the growth-rate parameter. The corresponding increase in weight (in Kg) of the stock is given by (equation 2):

$$\Delta w = a((l + \Delta l)^b - l^b),$$

with $a = 3.128958e^{-6}$ and $b = 3.277667619$ set as fixed and extracted from all the samples available in third and fourth quarters from 2003 to 2017. The growth functions described above calculate the mean growth for the stock within the model. In a second step, the growth is translated into a beta-binomial distribution of actual growths around that mean with parameters β and n. The first is fitted by the model as described in Taylor *et al*. (2007) and the second the second represents the number of length classes that an individual is allowed to grow in a quarter and it is fixed and equal to 5.

Initial abundance and recruitment

Stock population in numbers at the starting point of the simulation is defined as:

$$N_{a,l,1,1} = 10000\nu_a q_{a,l}, \quad a = 0, \ldots, 3, l = 3, \ldots, 20$$

Where ν_a is an age factor to be calculated by the model and $q_{a,l}$ is the proportion-at-length group l that is determined by a normal density with a specified mean length and standard deviation for each age group. Mean length-at-age (μ_a) and its standard deviation (σ_a) were extracted from all the data available from 1989 to 2016, including three surveys that are not included in the model: *ARSA*, *ECOCADIZ-RECLUTAS* and *SAR* surveys (see Table H.1.5.1). The mean weight-at-age for this initial population is calculated by multiplying a reference weight corresponding to the length by a relative condition factor assumed as 1. This reference weight-at-length was calculated using the formula $w = al^b$, with a and b as defined before. In Gadget files, this was specified as a normal condition distribution (*Normalcondfile*).

Similarly to the process of calculate the initial abundance described above, the recruitment specifies how the stock will be renewed. Recruits enter to the age 0 population at quarters 2, 3, 4 (because of the Gadget order of calculations for each time-step this is equivalent to have recruitment one quarter later, i.e. in quarters 3,4 and 1 of the next year) of all years, respectively, as follows:

$$N_{0,l,y,t} = p_{l,t} R_{y,t}, \quad t = 2, 3, 4, l = 3, \ldots, 15,$$

where $R_{y,t}$ represents recruitment at year y and quarter t; and $p_{l,t}$ the proportion in length group l that is recruited at quarter t which is sampled from a normal density with mean (μ) and standard deviation (σ_t) calculated by the model. The mean weight for these recruits is calculated by multiplying the reference weight corresponding to the length by a relative condition factor assumed as 1. Reference weight-at-age was the same used to calculate the initial population mean weight-at-age explained above. In Gadget files, this was specified also as a normal condition distribution (*Normalcondfile*).

Fleet operations

In the model, the fleets act as predators. There are three fleets inside the model: two for surveys (*PELAGO* and *ECOCADIZ* acoustic surveys) and one for commercial landings including all fleets: Spanish purse-seine, trawlers, Portuguese purse-seine, and others. The main fleet is Spanish purse-seine representing more than 90% of all the catches from 2001 to 2016 and more than an 80% from 1989 to 2000. It is also the only fleet with a length distribution available, then it was decided to include all commercial reported data in the same fleet, which is mostly the Spanish purse-seine one.

Surveys fleets are assumed to remove 1 Kg in each of the quarters when the surveys take place, while the commercial fleet is assumed to remove the reported number of individuals each quarter. This total amount of biomass (for the surveys) or numbers (for the commercial fleet) landed is then split between the length groups according to the equations 3 and 4 respectively, as follows:

$$C_{l,y,t} = \frac{E_{y,t} S_{l,T} N_{l,y,t} W_l}{\sum_l S_{l,T} N_{l,y,t} W_l},$$

and

$$C_{l,y,t} = \frac{E_{y,t} S_{l,T} N_{l,y,t}}{\sum_l S_{l,T} N_{l,y,t}},$$

where $E_{y,t}$ represents biomass landed (in Kg) at year y, and quarter t in equation 3, and numbers landed in equation 4, W_l corresponds to weight-at-length, and $S_{l,T}$ represents the suitability function that determines the proportion of prey of length l that the fleet is willing to consume during period T; T = 1, 2, 3 where T = 1 corresponds to the period 1989–2000, T = 2 to 2001–2016 and T = 3 to 1989–2016.

For this model, the suitability function chosen for the fleet and surveys is specified in Gadget manual as an ExponentialL50 function (*expsuitfuncl50*), and it is defined as follows:

$$S_{l,T} = \frac{1}{1 + e^{\alpha_T (l - l_{50,T})}}$$

where $l_{50,T}$ is the length of the prey with a 50% probability of predation during period T and α_T a parameter related to the shape of the function, both parameters are estimated from the data within the Gadget model. The whole model time period (1989–2016) is split into two different periods for suitability parameters of the commercial fleet because of changes in size regulation for the fishery around 1995 that become effective around 2001.

H.1.5.1.2. Observation model

Data are assimilated by Gadget using a weighted log-likelihood function. The model uses as likelihood components two biomass survey indices: *PELAGO* and *ECOCADIZ* acoustic surveys, age–length keys from the commercial fleet (Spanish purse-seine), *PELAGO* and *ECOCADIZ* surveys, and length distributions for the commercial fleet, *PELAGO* and *ECOCADIZ* surveys (see **Table H.1.5.1.2.1** for a detailed description of the likelihood data used in the model).

Table H.1.5.1. List of symbols used in model specification.

Index	
a	Age, $a = 0,\ldots,3$
l	Length, $l = 3,3.5,4,4.5,\ldots,22$
y	Years, $y = 1989,\ldots,2016$
t	Quartely timestep, $t = 1,\ldots,4$
T	$T = 1$ for period 1989-2000, $T = 2$ for period 2001-2016
Parameters	
Fixed	
a	Parameter of weight-length relationship $w = al^b$, $a = 3.128958 \times 10^{-6}$
b	Parameter of weight-length relationship $w = al^b$, $b = 3.277667619$
μ_a	Initial population mean length at age $\mu_0 = 9.99, \mu_1 = 12.1, \mu_2 = 15.2, \mu_3 = 16.1$
σ_a	Initial population standard deviation for length at age $\sigma_0 = 0.836, \sigma_1 = 0.5, \sigma_2 = 1, \sigma_3 = 1.2$
M_a	Natural mortality, $M_0 = 2.21, M_1 = 1.3, M_2 = 1.3, M_3 = 1.3$
n	Maximum number of length classes that an individual is supposed to grow $n = 5$
Estimated	
l_∞	Asympthotic length, l_∞=30
k	Annual growth rate, $k = 0.0770501$
β	Beta-binomial parameter, $\beta = 5000$
ν_a	Age factor, $\nu_0 = 120000, \nu_1 = 81000,$ $\nu_2 = 0.125, \nu_3 = 3.3e - 07$
μ	Recruitment mean length, $\mu = 9.91079$
σ_t	Recruitment length standard deviation by quarter, $\sigma_2 = 3.05845$, $\sigma_3 = 1.64798$, $\sigma_4 = 4$
$l_{50,T}$	Length with a 50% probability of predation during period T, $l_{50,1}^{seine} = 10.6$, $l_{50,2}^{seine} = 11$, $l_{50,3}^{ECO} = 13.7$, $l_{50,3}^{PEL} = 13.1$
α_T	Shape of function, $\alpha_1^{seine} = 0.385$, $\alpha_2^{seine} = 0.86$, $\alpha_3^{ECO} = 1.03$, $\alpha_3^{PEL} = 0.596$
Observed Data	
$E_{y,t}$	Number or biomass landed at year y and quarter t
W_l	Weight at length
$I_{y,t}$	Observed survey index at year y and quarter t
$P_{a,l,y,t}$	Proportion of the data sample over all ages and lengths for timestep/age/length combination
$O_{a,l,y,t}$	Observed data sample for time/age/length combination
$x_{a,y,t}$	Sample mean weight from the data for the timestep/age combination
Others	
Δl	Length increase
Δw	Weight increase
Δt	Length of timestep
$N_{a,l,y,t}$	Number of individuals of age a, length l in the stock at year and quarter y and t, respectively.
$q_{a,l}$	Proportion in lengthgroup l for each age group
$R_{y,t}$	Recruitment at year y and quarter t
$p_{l,t}$	Proportion in lengthgroup l that is recruited at quarter t
$C_{l,y,t}$	Total amount in biomass landed by surveys and in number landed by commercial fleet
$S_{l,T}$	Proportion of prey of length l that the fleet/predator is willing to consume during period T
$\pi_{a,l,y,t}$	Proportion of the model sample over all ages and lengths for that timestep/age/length combination
$\mu_{a,y,t}$	Mean length at age for the timestep/age combination
U_t	Understocking for timestep t
lw_i and uw_i	Weights applied when the parameter exceeds the lower or upper bound
lb_i and ub_i	Lower and upper bound defined for the parameter
val_i	Value of the parameter

Table H.1.5.1.2.1. List of symbols used in model specification. Note that the *BOCADEVA* DEPM survey was not finally included in the base case model.

Data source	type	Timespan	Likelihood function
Commercial landings	Length distribution	All quarters, 1989-2016	See eq. 7
	Age-length key	All quarters, 1989-2016	See eq. 7
ECOCADIZ acoustic survey	Biomass survey indexes	Second quarter 2004, 2006	see eq. 6
		third quarter 2007, 2009, 2010, 2013-2016	
	Length distribution	Second quarter 2004, 2006	see eq. 7
		third quarter 2007, 2009, 2010, 2013-2016	
	Age-length key	Second quarter 2004, 2006	see eq. 7
		third quarter 2007, 2009, 2010, 2013-2016	
PELAGO acoustic survey	Biomass survey indexes	First quarter 1999, 2001-2003	see eq. 6
		second quarter 2005-2010 and 2013-2016	
	length distribution	First quarter 1999, 2001-2003	see eq. 7
		second quarter 2000, 2005-2010, 2013-2016	
	Age-length key	second quarter 2014-2016	see eq. 7
BOCADEVA DEPM survey	Biomass survey indexes	Second quarter 2005,2008	see eq. 6
		third quarter 2011,2014	

Biomass Survey indices

The survey indices are defined as the total biomass of fish caught in a survey. The survey index is compared to the modelled abundance using a log-linear regression with slope equal to 1 (*fixedslopeloglinearfit*), as follows (equation 6):

$$\ell = \sum_t (\log(I_{y,t}) - (\alpha + \log(N_{y,t}))^2$$

where $I_{y,t}$ is the observed survey index at year y and quarter t and $N_{y,t}$ is the corresponding population abundance calculated within the model. Note that the intercept of the log-linear regression, $\alpha = \log(q)$; with q as the catchability of the fleet (i.e. $I_{y,t} = qN_{y,t}$).

Catch distribution

Age–length distributions are compared using l length group at-age a and time-step y,t for both commercial and survey fleets with a sum of squares likelihood function (*sumofsquares*) (equation 7):

$$\ell = \sum_y \sum_t \sum_l (P_{a,l,y,t} - \pi_{a,l,y,t})^2$$

where $P_{a,l,t,y}$ is the proportion of the data sample for that time/age/length combination, while $\pi_{a,l,t,y}$ is the proportion of the model sample for the same combination, as follows (equation 8):

$$P_{a,l,t,y} = \frac{O_{a,l,y,t}}{\sum_a \sum_l O_{a,l,y,t}}$$

and (equation 9)

$$\pi_{a,l,t,y} = \frac{N_{a,l,y,t}}{\sum_a \sum_l N_{a,l,y,t}},$$

where $O_{a,l,y,t}$ corresponds to observed data.

When only length or age distribution is available, it is compared using equation 7 described above but considering all ages or all lengths, respectively.

Understocking

If the total consumption of fish by all the predators (fleets in this case) amounts to more than the biomass of prey available, then the model runs into "understocking". In this case, the consumption by the predators is adjusted so that no more than 95% of the available prey biomass is consumed, and a penalty, given by the equation 10 below, is applied to the likelihood score obtained from the simulation (Stefansson, 2003, section 4.1.)

$$\ell = \sum_t U_t^2$$

where U_t is the understocking that has occurred in the model for that time-step.

Penalties

The *BoundLikelihood* likelihood component is used to give a penalty weight to parameters that have moved beyond the bounds in the optimisation process. This component does specify the penalty that is to be applied when these bounds are exceeded.

$$\ell_i = \begin{cases} lw_i(val_i - lb_i)^2 & \text{if } val_i < lb_i \\ uw_i(val_i - ub_i)^2 & \text{if } val_i > ub_i \\ 0 & otherwise \end{cases}$$

Where lw_i = 10 000 and uw_i = 10 000 are the weights applied when the parameter exceeds the lower and 100 upper bounds, respectively, val_i is the value of the parameter and, lb_i and ub_i are the lower and upper bounds defined for the parameter.

H.1.5.1.3. Order of calculations

The order of calculations is as follows:

Printing: model output at the beginning of the time-step.

Consumption: by the fleets.

Natural mortality.

Growth.

Recruitment: new individuals enter to the population.

Likelihood comparison: Comparison of estimated and observed data, a likelihood score is calculated.

Printing: model output at the end of the time-step.

Ageing: If this is the end of year, the age is increased.

Because of this order of calculations the time-step of indices, age–length keys and length distributions of the surveys are defined in Gadget a quarter before.

H.1.5.1.4. Implementation, weighting procedure

Input data (Likelihood files) are prepared for Gadget format using the mfdb R package (developed by Jamie Lentin, Shuttle Thread Ltd., UK). Running and weighting procedures were implemented in R with the gadget.iterative function from *Rgadget* package (developed by Bjarki Elvarsson, Marine Research Institute, Iceland). This function follows the approach presented in Taylor *et al*. (2007) and in the appendix of Elvarsson *et al*. (2014) based on the iterative reweighting scheme of Stefansson (1998; 2003), which is summarized as follows:

Let w_r be a vector of length L with the weights of the likelihood components (excluding understocking and penalties) for the run, and $SS_{i,r}$; $i = 1,\ldots,L$, the likelihood score of component i after run r. First, a Gadget optimization run is performed to get a likelihood score ($SS_{i,1}$) for each likelihood component assuming that all components have a weight equal to one, i.e. $w_1 = (1, 1,\ldots, 1)$. Then, a separated optimization run for each of the components (L optimization runs) is performed using the following weight vectors:

$$\mathbf{w_{i+1}} = (1/SS_{1,1},\ldots,(1/SS_{i,1}) * 10000, 1/SS_{i+1,1},\ldots,1/SS_{L,1}), i = 1,\ldots,L.$$

Resulting likelihood scores $SS_{i,i+1}$ are then used to calculate the residual variance,

$$\hat{\sigma}_i^2 = SS_{i,i+1}/df^*$$

for each component, that is used to define the final weight vector as:

$$\mathbf{w} = (1/\hat{\sigma}_1^2,\ldots,1/\hat{\sigma}_L^2).$$

Where degrees of freedom df^* are approximated by the number of non-zero datapoints in the observed data for each component. Finally, the total objective function is the sum of all likelihoods components multiplied by their respective weights according to the vector w.

In order to assign weights to the individual likelihood components (see **Table H.1.5.1.2.1**) in the procedure described above, all the survey indices were grouped together.

The optimization algorithms converged in individual and weighted runs.

H.1.5.2. Remarkable model assumptions

The model was implemented quarterly from 1989 to 2016.

All commercial fleets where grouped into only one: The Spanish purse-seine which represents more than a 90 % of all the catches from 2001 to 2016 and more than a 80% from 1989 to 2000. It is also the only fleet with a length distribution available.

The parameters for weight–length relationship equation ($w = al^b$) were assumed fixed and defined as $a = 3.128958e^{-6}$ and $b = 3.277667619$. Those values were calculated from all the samples available in third and fourth quarters from 2003 to 2017.

Natural mortality-at-age was also considered fixed with M0 = 2.21 and M1, M2, M3 = 1.3.

There was a minimum landing size restriction from 1995, which was only effective until 2001. As a consequence, it was necessary to define different parameters for two different periods: one period from 1989 to 2000 and the other period from 2001 to 2016.

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