Socio-economic Impacts and Responses of the Fishing Industry and Fishery Managers to Changes in Small Pelagic Fish Distribution and Abundance

Supplementary Material

A. Overview of operations for each case study region

A.1 Africa

A.1.1 North-West Africa

Several Small Pelagic Fish (SPF) species are caught in North-West Africa, in the Eastern Central Atlantic region, such as round and Maderian sardinellas (*Sardinella aurita* and *Sardinella maderensis*, respectively), yellow and Cunene horse mackerel (*Caranx rhonchus* and *Trachurus trecae*, respectively), Atlantic chub mackerel (*Scomber colias*), bonga shad (*Ethmalosa fimbriata*), European sardine (*Sardina pilchardus*), European anchovy (*Engraulis encrasicolus*), Atlantic horse mackerel (*Trachurus trachurus*) and silver scabbard (*Trichiurus lepturus*). These species are caught inshore with purse seine and deep-sea with trawler, and the landings are mainly used for animal feed – approximately 63% of the catch, especially for Mauritania, Senegal and Gambia (Dème et al. 2023) – as fishmeal and fish oil, while the rest is intended for human consumption. SPFs are managed under Total Allowable Catches (TACs) based on Maximum Sustainable Yield (MSY) management targets.

Round sardinella (*Sardinella aurita*) historically dominated the SPF catch in North-West Africa from 1990 to 2015 (FAO 2023). This species performs seasonal alongshore migrations driven by upwelling variability across Morocco, Mauritania, Senegal, Gambia and Guinea Bissau. Rich in omega-3, it is an excellent source of high-quality protein, making it a significant contributor to the diet of Sahelian populations (Robinson et al. 2022). But the high-fat content of round sardinella also makes it a choice species for making fishmeal, for which demand is

constantly rising on the world market (Touron-Gardic et al. 2022) and recently, different models have shown alarming round sardinella stock situations. An examination of the historical round sardinella series and abundance indices shows that the stock is in a critical situation marked by strong overexploitation (FAO 2023). A similar pattern is observed for flat sardinella, Cunene horse mackerel, and bonga shad.

A.1.2 South Africa

The purse seine fishery for small pelagic fish is South Africa's largest fishery in terms of landed mass. The commercial fishery began in the 1940s, targeting primarily sardine (*Sardinops sagax*) for canning purposes and additionally catching Cape horse mackerel (*Trachurus capensis*). Following a pulse in sardine abundance and landings in the late 1950s to early 1960s and the rapid decrease in landings once that pulse passed, the net mesh size was reduced, and the fishery expanded to target European anchovy (*Engraulis encrasicolus*) recruits. Anchovy dominated the landings for almost three decades, reaching a maximum of around 600,000 tons landed in 1987-1988. There was another pulse in sardine abundance at the turn of the century; this pulse coincided with a period of high European anchovy recruitment and biomass with combined landings exceeding 500,000 tons between 2001 and 2005 before the sardine abundance decreased once again (e.g., de Moor et al. 2011). Sardine and anchovy remain the primary species targeted in this mixed fishery today, with red-eye round herring (*Etrumeus whiteheadi*) typically forming the third-highest landings.

The industry prefers to catch sardine adults, which can be canned or frozen for human consumption, bait, or pet food. These sardine products are more profitable than reducing the sardine to fishmeal. In contrast, anchovies are primarily available to the fishery as recruits during their autumn and winter southward migration along the West Coast of South Africa, and landings are reduced to fishmeal and oil. Sardines and anchovies school together as juveniles. Anchovy catches thus result in the unavoidable bycatch of juvenile sardines. However, the industry would

prefer a low juvenile sardine bycatch, allowing these fish to reach a can-able size before landing. The joint management of sardine and anchovy, to explicitly consider this trade-off between maximizing catch for both species, is necessary given these technological interactions (de Moor and Butterworth 2016).

The fishery is managed with TACs for sardine and anchovy. Bycatches and catches of the other species in this mixed fishery are managed with Total Allowable Bycatches (TABs) and Precautionary Upper Catch Limits (PUCLs). A limited number of 'right holders' are granted access to the fishery, each assigned a unique proportion of the annual anchovy and, separately, sardine TAC. The TAB and PUCL 'pools' are not allocated individually to right holders, but only sardine and anchovy right holders may land these other SPFs. Since the early 1990s, the TACs have usually been recommended using a joint Operational Management Procedure developed using Management Strategy Evaluation (e.g., De Oliveira et al. 1998; de Moor et al. 2011). However, in recent years, exceptional circumstances have resulted in some TACs being set using methods similar to the conventional best assessment approach (de Moor et al. 2022). Anchovy TACs have remained relatively high, at an average of 380,000 tons over the past decade, although landings have been lower, averaging 210,000 tons. In contrast, sardine TACs and landings have been low in the past five years, averaging 34,000 tons and 21,000 tons, respectively.

Round herrings are primarily targeted at the times of the year when sardine or anchovy are unavailable to the fishery. As the resource is currently estimated to be underexploited (de Moor 2023), the industry has been encouraged to take full advantage of the round herring catch limit, mainly when sardine and anchovy catch limits are low. A Harvest Control Rule has recently been adopted to automate the calculation of the PUCL, which allows for a maximum of 120,000 tons (DFFE 2023). The average landings in the recent decade have been 46,000 tons.

As hypotheses of spatial structure in the sardine population developed from a single homogeneous population into separate components (with some interchange) (Coetzee et al. 2008; Weston et al. 2015; Teske et al. 2021), forms of spatial management have been explored. This has particularly focused on reducing the exploitation levels on the West Coast, which were relatively high given the predominantly West Coast-based location of sardine processing infrastructure and the drop in biomass since the last boom, to some of the lowest levels in recorded history.

A.2 Asia

A.2.1 Japan

SPF caught in Japan mainly includes Japanese sardine (*Sardinops melanostictus*), Pacific (chub) mackerel (*Scomber japonicus*), spotted mackerel (*Scomber australasicus*), Japanese jack mackerel (*Trachurus japonicus*), Japanese anchovy (*Engraulis japonicus*), red-eye round herring (*Etrumeus teres*), and Pacific saury (*Cololabis saira*). As of 2022, the total catch of SPF, mainly Japanese sardine and chub mackerel, was about 1.3 million tons, accounting for about half of the total catch of fishery products in Japan (Ministry of Agriculture, Forestry and Fisheries of Japan 2023). About 70% of SPF is caught by purse seine fisheries, and much of the rest is caught by set nets. SPF is used mainly for human consumption (fresh or processed), animal feed, fish meal, and fish oil (Makino 2018).

Stock assessment of the SPF by the Japan Fisheries Research and Education Agency (FRA) is principally conducted in two areas separately: the Pacific Ocean (Pacific Stock) and the East China Sea and Sea of Japan (Tsushima Warm Current Stock) (Japan Fisheries Agency and Japan Fisheries Research and Education Agency 2023). Traditionally, fishery management in Japan has been conducted through input and technical control, such as limitations on the number and size of fishing vessels (Yatsu 2019). In addition, since 1997, a TAC system has been in place for Japanese sardine, mackerel (including chub mackerel and spotted mackerel), and Japanese jack

mackerel (Ohshimo and Yamakawa 2018; Hakala et al. 2023). Furthermore, the Fisheries Act was substantially revised in 2020, explicitly introducing management targets based on MSY and strengthening TAC management. The introduction of TACs for Japanese anchovy and round herring is currently under discussion. As TACs will be applied for more species than ever, more efficient and sustainable utilization of the whole species assemblage, including bycatch issues, will need to be addressed.

A.3 Europe

A.3.1 North East Atlantic

The SPF fisheries account for the most significant proportion of the total catch at the scale of the whole North East Atlantic. SPF caught include widely distributed stocks such as Atlantic mackerel (*Scomber scombrus*), Atlantic horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), herring (*Clupea harengus*) and sandeel (*Ammodytes spp*), and locally distributed stocks, mostly European sardine (*Sardina pilchardus*) and European anchovy (*Engraulis encrasicolus*) that are exploited by smaller-scale fisheries.

A.3.1.1 North East Atlantic (NEA) macro-region

The pelagic fisheries operating in the NEA macro-region comprise vessels from Faroe Islands, Greenland, Iceland, Norway, the United Kingdom, and the European Union. The primary SPF caught at the scale of the macro-region are Atlantic mackerel, Atlantic horse mackerel, blue whiting, and herrings (e.g., North East Atlantic herring and Atlanto-Scandian herring). Historically, these species have been mostly managed through TACs shared among countries, while disagreements have been present for particular species such as mackerel and horse mackerel. The allocation of quotas between the NEA coastal states has been based on some pre-agreed allocation keys (based on historical catch records). Additionally, the EU allocates the

quotas among its member states based on the relative stability principle (as defined in the EU Common Fisheries Policy, based on historical catches). Within countries, each one manages and allocates its fishing rights differently (e.g., individual vessel quotas v/s individual transferable quotas). The stock status of all species harvested in the NEA is currently healthy, except for horse mackerel, whose stock has declined since 2000 (Hougaard et al. 2020; Østhagen et al. 2020), and currently, there is a zero catch advice for 2023-2024.

A.3.1.2 Bay of Biscay

The Bay of Biscay (ICES sub-area 27.8) lies along the western coast of France (Division 27.8.a and b) and the Northern coast of Spain (Division 27.8.c). France and Spain are almost the only two countries exploiting these waters. Based on SPF availability in the area and migratory dynamics, the Bay of Biscay pelagic fishery targets species sequentially throughout the year. Consequently, vessels change gear throughout the year depending on the species targeted. However, Spain's SPF fleets mainly consist of purse seiners, while French fleets include purse seiners and pelagic trawlers.

The most commonly harvested SPF in the Bay of Biscay are European anchovy, European sardine, Atlantic mackerel, and Atlantic horse mackerel – both mackerels are also targeted in the NEA macroregion (see Section A.3.1.1), while all these species, except for Atlantic mackerel, are also caught in Portuguese Iberian waters (see Section A.3.1.3) – over the recent decade (2013-2021), sardines have dominated French landings of SPF in the Bay of Biscay, with an average landings of approximately 15,000 tons per year, which corresponds to 64% of French SPF landings (European Commission et al. 2023), while anchovy and mackerel represent most of the Spanish landings, with average landings of approximately 21,000 to 24,000 tons per year, respectively, corresponding to 68% of Spanish SPF landings.

The European anchovy is an emblematic species of the Bay of Biscay that has been exploited for more than one century by French and Spanish fisheries (Junquera 1984; Uriarte et al. 1996;

Petitgas 2010). Anchovy catches have displayed dramatic fluctuations over this period that were identified as a consequence of changes in oceanographic conditions on the stock dynamics (e.g., Junquera 1988). There is currently a management plan for anchovy that includes technical measures and a definition of TAC based on harvest control rules co-defined by the Scientific, Technical and Economic Committee for Fisheries and the Southwest Waters Advisory Council, and considering early recruitment indicators. The design of this management plan for sustainable exploitation of a SPF under recruitment uncertainty is unique in Europe (Uriarte et al. 2023).

The European sardine also has a long exploitation history and cultural importance in the Bay of Biscay and, similar to anchovy, has displayed, but with different timing, tremendous fluctuations in its dynamics that impacted French and Spanish fisheries (Durand 1991; Cendrero 2002). Historically, the fleet has focused on the southern stock distributed around the Cantabrian Sea and Atlantic Iberian waters (see next section A.3.1.3). However, the regime shift in the productivity of this stock that occurred around 2006 motivated a change in the exploitation pattern of the fishery, with vessels starting to target the northern stock (Division 27.8.a and b) more intensively. ICES provides advice for the total catch of sardine stocks following the MSY approach despite a precautionary management plan for 2021-2026 that was agreed between Portugal and Spain for the southern stock. No global management of the northern sardine stock is implemented, but local rules regarding the size of landed fish and the total amount of catch exist in some fisheries. These rules are implemented to prevent a market price drop and comply with the ecolabelling standards.

The Atlantic mackerel stock appears in the Bay of Biscay in the first part of the year. Despite the importance of this stock for the Spanish fleets, the Spanish quota is low compared to the demand. In 2009, this led the fleets to fish almost four times their quota. The EU sanctioned the overshoot, and the fleets have had to deduct the extra mackerel catch from their anchovy and mackerel quotas from 2013 to 2023. Since 2013, ICES has provided catch advice based on the

MSY approach. However, the absence of agreement between the Coastal States (since 2009) has regularly resulted in exceeding the advised catch (ICES 2023a).

French and Spanish purse seiners mainly harvest the Northeast Atlantic horse mackerel that inhabit the Bay of Biscay. Contrary to the other SPF harvested in the area, it has historically been used for fishmeal production, but presently, a more significant proportion goes to human consumption (ICES 2023b). An international agreement for horse mackerel management has only been reached between the EU and the UK. It relies on a TAC whose values are recommended by ICES based on the MSY approach and the long-term management plan proposed by the Pelagic Advisory Council.

A.3.1.3 Portuguese Iberian Waters

The purse seine fishery is Portugal's most important fishery in terms of historical significance and economic value. In 2019, it accounted for nearly half of the country's total fish landings by weight (DGRM 2020). The purse seine fleet comprises 160-180 vessels, with around 12,000 yearly trips (Silva et al. 2015). Most vessels are dedicated to purse seining, while smaller ones use this method seasonally when demand and sardine prices are higher (Gonçalves et al. 2008; Feijó 2013; Feijó et al. 2018). Daily trips are short, lasting approximately nine hours on average and taking place near fishing ports and within the shallower half of the continental shelf (Stratoudakis and Marçalo 2002; Silva et al. 2007; Feijó 2013; Feijó et al. 2018).

The purse seine fishery primarily targets SPF, with European sardine being the key resource for the canning industry and fresh consumption in Portugal. Sardines have historically been the primary target of fishing and landings in Portugal (Mendes and Borges 2006; Borges et al. 2003). Sardines hold significant cultural importance among the Portuguese people, who consume them in substantial quantities per capita and feature them prominently in various important summer religious festivities. From 2005 to 2012, sardines represented 70% of Small Pelagic Fish (SPF) and Medium Pelagic Fish (MPF) landings, with approximately 50,000 tons per year. Other

targeted species include Atlantic chub mackerel, Atlantic horse mackerel, and European anchovy (DGRM 2021a). Anchovy and horse mackerel represented a smaller proportion of the landings, with approximately 3,000 tons and 4,600 tons per year from 2005 to 2020, respectively, accounting for 5% and 7% of the SPF landings. Meanwhile, chub mackerel landings have become more relevant in recent years, becoming a substitute for sardine. As of 2020, sardines accounted for 31% of the SPF landings, while chub mackerel constituted 40% (DGRM 2021a).

The southern stock of European sardine, known as the Atlantic Iberian sardine stock in ICES divisions 27.8.c and 27.9.a (Cantabrian Sea and Atlantic Iberian waters), encompasses the region from the Gulf of Cadiz in the South, along the entire Portuguese coast (ICES area 27.9.a), and extends along the Spanish coast up to the inner Bay of Biscay in the North (ICES area 27.8.c) (Silva 2003, 2007; Silva et al. 2008; ICES 2017). Most sardine landings (99%) are made by purse seiners (ICES 2022a). The abundance of sardines is closely linked to recruitment. Poor recruitment has strongly influenced the evolution of the stock (Silva et al. 2008, 2015; Malta et al. 2016; ICES 2017), with no significant recruitment observed in the southern stock since 2004, with an exception in 2019 and 2022, where the size of the stock was assessed to be above the limit reference point and the precautionary reference point thresholds. However, ICES considers that the stock is still in a low productivity regime (ICES 2022b). In contrast to the northern stock harvested in the Bay of Biscay (see previous section A.3.1.2), where no global regulations are in place, the southern sardine stock is managed through minimum landing size, gears and usage regulations, technical measures, and seasonal closures (ICES 2022a).

Atlantic chub mackerel is a medium pelagic fish (MPF) found in warm and temperate waters of the Northeast Atlantic, as well as in the Eastern Central Atlantic (see Section A.1.1). Over the past 15 years, Portuguese landings of chub mackerel have shown a significant exponential increase and currently stand at approximately 80,000 tons per year. Most of these landings originate from the southwestern and southern waters, specifically in ICES subdivisions 27.9.a.Central South and 27.9.a.South in Algarve (ICES 2020). Purse seiners constitute the

primary fishing method for capturing chub mackerel, accounting for approximately 75% of the total landings. This species has several destinations, used for fresh human consumption but a significant part is used like fish meal feeding tuna (Ramos and Lino 03 2022) and bait (to substitute sardine) for black scabbardfish (*Aphanopus carbo*) fishery (Bordalo-Machado and Figueiredo 2009). This species has become an essential resource for the purse seine fishery, partially compensating for the reduced fishing opportunities for sardines in Iberian waters (ICES 2020).

Atlantic horse mackerel is an MPF found in the Northeast Atlantic, including Madeira and the Mediterranean Sea. In ICES division 27.9.a, the horse mackerel is exploited by Portugal and Spain, using three types of gears or fleets: bottom trawl, purse seine, and artisanal (ICES 2022c). The bottom trawl and purse seine fleets tend to catch a higher number of juvenile individuals and a lower abundance of adults. Horse mackerel is a significant target species for the bottom trawl fleet, accounting for approximately 43% of their catches in 2021. The purse seine fleet accounted for around 50% of the catches, while the artisanal fleet contributed approximately 7%. Notably, the purse seine fleet in Portugal has seen an increase in the relative importance of horse mackerel in annual catches, particularly in recent years. This shift can be attributed, in part, to the reduced catch opportunities for the Iberian sardine stock in ICES divisions 27.8.c. and 27.9.a (ICES 2022b).

European anchovy is a SPF found along the coasts of the North Sea to Southeast Africa, encompassing the entire Mediterranean basin. For management purposes, anchovy has been divided into two distinct stock units. One is found in the Bay of Biscay (see Section A.3.1.2), while the other is distributed in ICES divisions 27.9.a, which includes the Portuguese coast and Spanish waters of the Gulf of Cadiz. As already mentioned in Section A.3.1.2 about the Bay of Biscay fishery, this species is of significant importance for fisheries and economic activities in countries bordering the Iberian Peninsula and the Mediterranean Sea (Uriarte et al. 1996; Lleonart and Maynou 2003). Anchovy holds market value, supports substantial production, and

has a wide distribution across various East Atlantic and Mediterranean countries, making it a significant regional shared resource. There is no stock assessment of anchovy in more northern areas, as the stock limits were primarily established based on administrative considerations. In ICES Division 27.9.a, purse seiners are the primary fishing method used to harvest anchovy, accounting for approximately 99% of total landings. Since 2016, most catches and landings have been taken in western Iberia, with over 90% concentrated in ICES Subdivision 27.9.a.Central North (ICES 2022a).

In Portugal, among the SPF and MPF targeted by purse-seiners, Atlantic horse mackerel and European anchovy are regulated by TACs (ICES 2022c, 2023c). The TACs for these species are established based on scientific assessments and management considerations. The annual sardine quota is agreed upon between Portugal and Spain through bilateral negotiations (ICES 2022b). The management of the sardine fishery involves implementing various measures, including catch limits, seasonal closures, and area-based management, to ensure the sustainable exploitation of the stock (Silva et al. 2015; DGRM 2021b). Chub mackerel does not have a specific quota or a formal stock assessment model in place (ICES 2020). The management of the chub mackerel fishery is primarily based on general fisheries management principles and measures applied to the overall pelagic fishery.

In the purse seine fishery in Portugal, a sequential targeting approach is employed, where different species are fished throughout the year based on their fishing quotas, availability in the fishing grounds, and migratory patterns. Until 2012, the fleet used to fish near home using the same fishing grounds, mainly to catch sardines (Feijó et al. 2022). Harvesters in purse seine fisheries collaborate closely to ensure sustainable fishing practices and maintain competitive market prices. They work together to regulate catch and landing levels, aiming to strike a balance between meeting market demand and preserving the long-term viability of the fishery.

A.3.2 Southern Tyrrhenian Sea, Italy

In the Southern Tyrrhenian Sea, which is part of the Mediterranean Sea corresponding to the Geographical Sub Area 10 (GSA10), European anchovy is the main SPF species targeted commercially.[1] Landings have decreased drastically from 8,000 tons landed in 2010 to approximately 1,500 tons in 2021 (European Commission et al. 2023). While the GSA10 is characterized by a total surface area of about 39,000 nmi^2, the continental shelf, which is the most frequently fished area, is only about 2,317 nmi^2. This stretch of the Mediterranean Sea borders five coastal Italian regions, even though the main fishing fleets targeting SPF are in the northern and southern parts of the GSA10, in Campania and Sicily.

Other typical SPFs targeted, although caught in lower quantities and mainly in autumn, are European sardines and round sardinella. These species are primarily sold as bait for longliners targeting large pelagics. The bulk of the SPF landed is caught by purse seiners (15 to 24 meters of length overall) following a specific temporal pattern; most fishing activities are carried out in spring and summer, mainly due to suitable weather and market conditions. In addition, a second fleet (>24 meters in length overall) accounts for fewer vessels that primarily target Atlantic bluefin tuna (*Thunnus thynnus*) and other tuna-like species but sporadically target anchovy. Another traditional fishing gear used for targeting anchovies is a small-scale driftnet called "Menaide." This traditional fishing gear has remarkable social and cultural importance for local communities and is used in a small area of the Campania region (Cilento coast). For anchovy in GSA10, the only management regulation is the minimum landing size (9 cm), and the application of a TAC is not foreseen. According to the EU policies, the commercial fishery must also compile an electronic logbook, recording information about catches and landings operations.

[1] For statistical and management purposes, the Mediterranean Sea is divided into 27 Geographical Sub Area (GSA), and six of them are routinely exploited by the Italian fishery.

A.4 North America

A.4.1 U.S. West Coast

The SPF fishery dates back to the late 1800s when Pacific sardine (*Sardinops sagax*) was targeted as bait (Pomeroy et al. 2002). The commercial sardine fishery became established during the next century when canning sardine was successfully introduced, helping to overcome the decline of salmon for canning (Pomeroy et al. 2002). The consolidation of the fishery, which at the time was unregulated, was also aided by the introduction of the lampara net and purse seine net (McEvoy 1986). In the meantime, a small fishery for Northern anchovy (*Engraulis mordax)* was also developing. The fishery was referred to as the *wetfish* fleet and also fished for other species besides anchovy and sardine, such as Pacific chub mackerel (*Scomber japonicus*), Jack mackerel (*Trachurus symmetricus*), Pacific bonito (*Sarda lineolata*), Pacific bluefin tuna (*Thunnus orientalis)*, and market squid (*Doryteuthis opalescens*) (PFMC 2020). However, the Pacific sardine remained the main target species, with most sardines caught going into canning or reduction until its collapse in the late 1940s and its closure in 1967 (Radovich 1982). The Pacific sardine fishery reopened in 1986 with a precautionary quota of 906 tons and was considered fully recovered in 1998 with an estimated biomass of over one million tons (PFMC 2020).

Currently, the Pacific sardine commercial fishery is managed by a TAC and limited entry and has been closed for the whole U.S. West Coast since 2015 as the stock biomass (SSB) is estimated to be below the Harvest Control Rule cutoff point of 150,000 tons. This total closure came after many years of seasonal closures. In recent years, the purse seine fleet has switched to squid, even moving north to Oregon following the species' distribution shift. Market squid are currently the primary source of revenue in this fishery, and they are priced higher than other forage species (e.g., sardine and anchovy). The Northern anchovy fishery has lost its importance within the Coastal Pelagic Species (CPS) complex as there is no reduction capacity for the Northern anchovy fishery in California. However, anchovy can be seasonally important in some

particular ports like Monterey, where it is the only species that harvesters can harvest when both market squid are unavailable and the Pacific sardine fishery is closed (PFMC 2020).

A.4.2 U.S. East Coast and Gulf of Mexico

The SPF fishery in the U.S. East Coast and Gulf of Mexico is composed mainly of purse seiners. The two main species targeted in this region are the Gulf menhaden (*Brevoortia patronus)* in the Gulf of Mexico and Atlantic menhaden (*Brevoortia tyrannus*) along the U.S. East Coast. These two species do not have market value for direct human consumption, with approximately 70% of the Atlantic menhaden and nearly 100% of the Gulf menhaden catch processed for reduction each year (SEDAR 2018, 2020). Reduction fishery products include fish meal used in aquaculture feed or animal food, soluble products for additives, and fish oil. For Atlantic menhaden, approximately 30% of the catch, generally in the north, is caught for use as whole or cut bait. Besides purse seine, the bait fishery uses pound nets and other assorted gear. The lobster and blue crab fisheries use part of the catches as bait. Harvesters may alter or focus their fishing in the season based on market conditions (due to regulations, the Atlantic season currently begins in May or June and ends on December 31st; the Gulf of Mexico season runs from the third Monday in April until November 1st). However, the number of reduction processing facilities has been decreasing due to a combination of factors, such as storm resilience and odor abatement issues.

A coastwide TAC has been implemented for Atlantic menhaden to maintain the stock of forage species that sustains other fisheries, such as striped bass (ASMFC 2019; SEDAR 2020); no TAC has been implemented in the Gulf of Mexico. The TAC allocation was based on historical landings, and the reduction portion of the TAC is usually harvested. When the reduction allocation of the TAC is not harvested, it is generally due to weather constraints, such as tropical storms, at the end of the traditional season. The bait portion is often not wholly harvested due to the TAC division among states, some of which may not have a well-developed

fishery or currently do not harvest any Atlantic menhaden. Other regulations imposed in both the Atlantic and Gulf of Mexico menhaden fisheries include spatial closures for the reduction fleet and caps on harvest for specific (not coastwide) areas. Shifts in the Gulf menhaden fishery have occurred annually due to yearly changes in the hypoxic zone in the Gulf of Mexico (Langseth et al. 2014).

A.4.3 Mexico Northwest Coast

In Mexico, the small pelagic fishery began in the port of Ensenada, Baja California, in the late 1940s and early 1950s after the collapse in catches on the North American coasts. Later, other areas further south began to be explored: Cedros Island, Magdalena Bay, and in the late 1960s and early 1970s, the Gulf of California was incorporated (Félix-Uraga 2006; Nevárez-Martínez et al. 2023). Today, due to catch volumes, the small pelagic fishery is the most important, contributing up to 50% of national fishing and aquaculture production, and this basically develops in the northwest of the Mexican coast, including the Gulf of California (DOF 2019; Enciso-Enciso et al. 2022).

The Gulf of California's Pacific sardine (*Sardinops sagax*) fishery is Mexico's largest fishery by volume, with approximately 85% of total landings used for reduction into fishmeal – other species targeted are thread herring (*Opisthomnema spp.*), Pacific anchoveta (*Cetengralus mysticetes*), Pacific chub mackerel (*Scomber japonicus*), Northern anchovy (*Engraulis mordax*), red-eye round herring (*Etrumeus teres*) and leather jackets (*Oligoplites spp*). Since the inception of a large-scale purse seine fishery in the late 1960s, small-pelagic fishery landings in Northwest Mexico have been highly variable, with declines of Pacific sardine associated with El Niño-Southern Oscillation (ENSO) events considered a dominant driver (Nevárez-Martínez et al. 2021). Historically, as much as 80% of small-pelagic fishery landings have occurred within the highly productive northern and central regions of the Gulf of California.

The Pacific sardine fishery has been MSC certified since 2011 (Christian et al. 2013), as managed by a minimum length size limit, limitation on fishing gear and capacity, and the establishment of closed areas and seasons. Biological sampling (Felix-Uraga et al. 1996), fisheries records and reports (Rodríguez-Sánchez et al. 2001; Lluch-Belda et al. 2003), and scale depositions (Holmgren-Urba and Baumgartner 1993) suggest significant interchange between the Gulf sardine population, and those found in the Soledad Basin (in the Pacific Ocean just north of Magdalena Bay) and the Santa Barbara Basin, with many newer, larger fishing boats having the capacity to fish on both sides of the Baja California Peninsula. Though conventional wisdom suggests that environmentally driven changes in recruitment primarily drive regional SPF biomass (Lluch-Cota et al. 1999; Nevárez-Martínez et al. 2001), a source of ongoing debate concerns the degree to which sustained fishing pressure during periods of resource decline and/or environmental variability may function to limit stock productivity (Giron-Nava et al. 2021) and have cascading impacts on regional marine ecosystems (Velarde et al. 2004; Gilly et al. 2022) and small-scale fisheries livelihoods (Frawley et al. 2019). During recent El Nino events in 1997/98 and 2014/15, landings of Pacific sardine declined as much as 90% due to changes in stock distribution and recruitment failures.

A.5 South America

A.5.1 Peru

The anchoveta (*Engraulis ringens*), or Peruvian anchovy, is a small pelagic fish inhabiting the coast of Peru and Chile. Anchoveta represents about 60% of Peruvian landings, with an average of four to five million tonnes per year in the 21st century, being the primary SPF targeted in the country (FAO 2020). The industrial fishery started in the 1960s, and it had a major collapse after the mid-1970s due to overfishing in combination with a strong 1972-1973 El Niño that produced an almost total failure in recruitment (Boerema and Gulland 1973). Before its collapse, landings

averaged about eight million tons annually and peaked at twelve million in 1970, with insufficient management measures to control fishing efforts (Boerema and Gulland 1973). From the late 1970s to the beginning of the 1990s, there was an increase in Pacific sardine availability, incentivizing harvesters to switch species (Cárdenas-Quintana et al. 2015). The anchoveta stock recovered in the mid-1990s, followed by a collapse of the sardine fishery after the 1997-1998 El Niño, exacerbated by the associated juvenile sardine bycatch in the now-growing anchoveta fishery, particularly during the reduced availability of anchoveta during the 1997-1998 El Niño (Cardenas et al. 2015).

In the 2010s, anchoveta dominated the SPF fisheries, with around four million tons of landings annually. Currently, a TAC is in place, and the quota is managed under an individual semi-transferable catch-share system (Oliveros-Ramos et al. 2021). The fishery opens twice yearly, and the quota is fished in approximately four to six weeks. Two fishing seasons per year, with different management measures, are organized around two reproductive closures during the main spawning peaks (Oliveros-Ramos et al. 2021). During the reproductive closures, the Peruvian Marine Research Institute (IMARPE) carries out an ecosystem survey that provides information for the stock assessment, which comprises a projection of the current state of the population until the beginning of the next reproductive season. This short-term forecast, lasting between three and five months, is carried out twice yearly and explicitly considers environmental variability and uncertainty, as forecasted by a national multisectoral technical committee created for that specific purpose.

The fishery currently produces around one million tonnes of fish meal and 100,000 tonnes of fish oil, with a value of over one billion US dollars per year, providing jobs in the order of tens of thousands and hundreds of thousands for direct and indirect jobs, respectively. Anchoveta inhabits the neritic zone, with a more coastal distribution than other small pelagics like sardine and chub mackerel. Vessels have refrigeration technologies, yet the fleet focuses principally on fishing anchoveta for reduction, with only a minor part of their catch intended for human

consumption. The artisanal purse-seine sector also catches SPF, averaging 50,000 tons of anchoveta annually. They are not obliged to report their relatively low landings, and these are not considered catch data in the stock assessment. There is also a ban on fishing within five nautical miles of the coastline, as small anchovies concentrate closer to the coast, and fishing closures are enforced during main reproductive periods. Additional temporal fishing closures, lasting between a few days and a week, are set in areas where a high concentration of juveniles is reported from on-board monitoring of the fishing vessels (Oliveros-Ramos et al. 2021). Additionally, a juvenile TAC has been in place since 2016, allowing a closure of the fishing season if the juvenile TAC is reached before the total TAC.

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