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Original Article

Revealing the adaptation strategies of pelagic fleets in the Bay of Biscay by combining fishery data and fishers' knowledge

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Abstract

The French pelagic fishery in the Bay of Biscay is currently facing new challenges. To anticipate and support future adaptations of fishers' strategies, we proposed to scrutinize fishers' past behaviours and determine the driving factors of their adaptations using a combination of quantitative and qualitative analysis. Annual strategies deployed by the pelagic fleet between 2010 and 2018 were identified through fishing data. Individual sequences of strategies used by vessels then served as a basis for the definition of a new fleet segmentation, revealing behavioural patterns and bridges between strategies. Fishers from two segments were then interviewed to identify the factors underlying their decisions at four different time scales. Fishers surveyed felt in control of both long-term (pluri-annual) and short-term (daily) decisions. Social aspects and personal preferences were found to be preponderant at these time scales. On the contrary, seasonal and annual activities were perceived as being dictated by market opportunities and ecological cycles. We showed that fishers were forced toward a greater dependence on sardine by regulatory constraints and the lack of opportunities on other species. Our study draws perspective by combining historical fishery data analysis with fisher's experiential knowledge to understand fishing behaviours.

Keywords: Fishers' strategies; fleet dynamics; fleet typology; small pelagics; fishing behaviour; Bay of Biscay

Introduction

Concerns about small pelagic fishes (hereafter SPF) are re-emerging in the Bay of Biscay (hereafter BoB). The length and weight of sardines and anchovies have clearly declined over the last decade (Doray et al. 2018), and the sardine stock is showing signs of overexploitation (ICES 2024). SPF populations are highly sensitive to environmental variability, making them a highly fluctuating resource (Véron et al. 2020). The recent history of SPF in French waters has been marked by several collapses that have severely affected the associated fisheries. Two recent examples were the anchovy fishery closure between 2005 and 2010 in the BoB and the collapse of the French Mediterranean sardine fishery in the early 2000s (Saraux et al. 2019).

The Bay of Biscay is particularly important for the French sardine fishery. In 2021, 21 026 tonnes of sardines were landed in the BoB, representing 11% of the total landings in this area (Ifremer 2024). On the other hand, anchovy landings by French vessels have remained low since the reopening of the fishery in 2010 compared to pre-closure levels (ICES 2022).

Currently, the management of SPF fisheries in the BoB is diverse. Anchovy, mackerel, and horse mackerel are subject to European quotas managed locally by Producer Organizations (PO) (Larabi et al. 2013). Access to the anchovy fishery is also restricted by a European license requirement. However, the sardine fishery is unregulated, except for the introduction of a maximum number of purse seiners vessels in the northern BoB.

The stock assessment for sardine shows that fishing pressure has increased since 2010, exceeding the precautionary approach reference point. Simultaneously, spawning stock biomass has decreased below the precautionary approach value (ICES 2024). This context stresses the need for a management plan to prevent a new crisis and preserve, together, the SPF resource, the fishery, and the related industries (mainly canneries). Designing a management plan requires a good understanding of population dynamics, but also of the economic and social incentives and constraints of fishing communities (Branch et al. 2006, Beddington et al. 2007). Indeed, the unexpected response of fishers to the implementation of management measures is recognized as a major cause of management failure (Fulton et al. 2011).

Fishing activity results from choices made by fishers about which species to target, with which gear, and on which ground on a daily basis and/or according to longer-term planning. These choices are driven by individual preferences and by the context of the fishery (Kraan et al. 2023). This context is a complex mix of economic, environmental, regulatory, and social opportunities and constraints. Pelagic fisheries are particularly accustomed to adapting to the changing conditions of the resource and are recognized as more adaptive and capable of risk-taking (Girardin et al. 2017). However, the example of the 2005 anchovy crisis in the BoB provides a contrast, as French landings never returned to their pre-closure levels, contrary to Spanish landings. The reasons for these marked differences in their level of resilience have not been clearly established (Andrés and Prellezo 2012). They are likely to be multifactorial (Cinner et al. 2018), combining fishers' personal situations (retirement, debt), technical abilities (skills related to other species or gear), economic opportunities (eligibility for decommissioning plan, availability of market for other species), and management constraints (quota/license availability). Understanding these characteristics, drivers, and constraints would help to assess the ability of the Bay of Biscay pelagic fleets to adapt to a new crisis and provide guidance to improve their resilience. On the other hand, it would help anticipating their future responses and therefore increase the likelihood of future management success.

Fishers' behaviour has been studied from many angles (Andrews et al. 2021). Different time scales can be used, from short-term to long-term behaviour (Vermard et al. 2008). Different categories of factors have been explored. Economic factors are largely dominant in the literature, regarding both long-term and short-term behaviour (Mardle et al. 2006, Vermard et al. 2008, van Putten et al. 2012). Social and personal contexts are also often examined (Christensen and Raakj 2006, Murray and Ings 2015). Another set of factors influencing fishers' activity rely on the regulatory context, from quotas (Anderson et al. 2017) to the local management overseen by the PO (Le Floc'h et al. 2015).

To explore fishers' behaviour, many studies have emphasized the need to assess all these factors at stake, without neglecting the social and personal context (van Putten et al. 2012, Andrews et al. 2021, Schadeberg et al. 2021, Kraan et al. 2023). To this end, interdisciplinary approaches are recommended. In line with this recommendation, our study proposes an original combination of quantitative and qualitative approaches.

We first explored the fishing activity of vessels targeting SPF in recent history (2010–2018). Common patterns in fishing activity among vessels can provide proxies for fishers' behaviour or adaptation possibilities (Andrés and Prellezo 2012, Andrews et al. 2021, Schadeberg et al. 2021). To summarize these patterns, we relied on two concepts: annual fishing strategies, which describe a vessel's fishing activity in a given year, and vessel trajectories, which are the sequences of strategies implemented by a vessel year after year. Annual strategies were determined following a clustering method on fishing trips. To analyse annual strategies, we asked the following questions: Are fishing strategies linked to the technical characteristics of vessels? What are the dynamics of these strategies in recent history and have strategies disappeared while others have emerged? With a second clustering step, we grouped vessels with a similar set of strategies used during our study period to propose an innovative classification of the fishing fleet. Our questions here were: what past adaptations of vessels were revealed by this classification? And is it possible to explain them by looking at a vessel's characteristics and past events in the fishery?

The second step of this study attempts to explore and rank a large range of factors that could explain these past behaviours using semi-structured interviews. In this second step, the specific questions we asked were: At what scale do fishers make decisions? Are the factors underlying these decisions similar across vessels and fleets? Across time scales? Were the factors perceived by fishers as determinants the same as those reported in the literature?

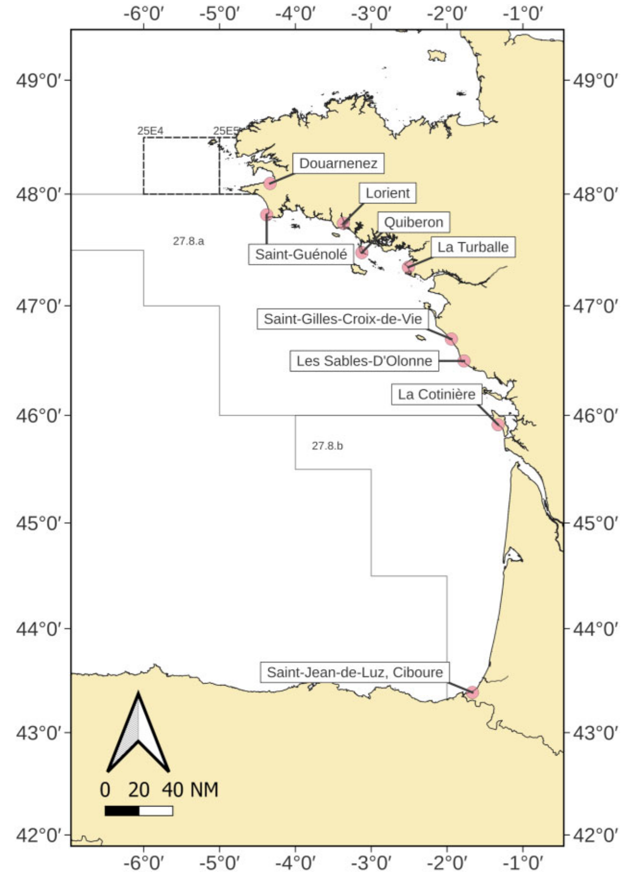

Figure 1. Map of the study area (ICES areas 27.8.a and 27.8.b, ICES rectangles 25E4 and 25E5). Origin harbours of the vessels included in our study fleet are indicated with dots.

Materials and methods

Classification of vessels targeting SPF

Study period, area, and fleet

Fleet adaptation and behaviour were studied during the 2005 to 2010 anchovy fishery closure in the BoB (Vermard et al. 2008, Andrés and Prellezo 2012). We chose to focus our study on the period following the reopening of the anchovy fishery in the BoB, starting in 2010 and ending with the last year of consolidated fishery data (2018) at the time this study was conducted (2020).

Our study area (Fig. 1) consists of ICES areas VIIIa and VIIb, and the Iroise Sea (statistical rectangles 24E4 and 24E5, ICES areas VIIh and VIIe). The Iroise Sea is classically added to the BoB when studying SPF, for instance, in the ICES stock assessment based on stock units and fleet extension (ICES 2022).

Individual vessels in our study fleet are defined as a boat-owner couple. If the ownership of a vessel changed during our study period, a new vessel was created. Our study fleet was constructed to include all vessels with a significant dependence on SPF or a significant contribution to landings. A

Table 1. Description of metrics used to determine annual fishing strategies and the source of the data.

Aspect	Data source	Description and metrics used to reflect the aspect
Main métier	Ifremer's fishery information system (SIH).	The two main fishing métiers practiced by the fishers are informed monthly in activity calendars. To limit the number of variables, we deleted less practiced métiers, i.e. métier practiced <8 months in total by the whole fleet during the study period (one month per year in average) AND practiced fewer than three months in a year by a particular vessel (to avoid deleting a métier structuring for a vessel). In the trawler group, 67 métiers were kept out of 99. In the purse seiners group, 15 métiers were kept out of 22. The metric is therefore the number of months in the year the métier was a main métier over the number of the vessel's active.
Seasonal species panel	French government (DGAMPA) and Ifremer's fishery information system (SIH). Data treatment by Ifremer (SIH).	For each season, we calculated the proportion of each species or group of species in the vessel's landed value. Over the main twenty species landed by our vessels, the six largest volumes (>5% of the landings each) are considered individually: sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*), albacore (*Thunnus alalonga)*, sea bass (*Dicentrarchus labrax*), hake (*Merluccius merluccius*), and nephrops (*Nephrops norvegicus*). Based on expert knowledge, we also considered Bluefin tuna (*Thunnus thynnus*) individually, as it represents a strategic species for a small number of vessels. The other 13 species were gathered into pelagics (mainly horse mackerel and mackerel) or demersals. Finally, all the other species are gathered in one group (5% of total landings).
Number of species representing 80% of the landings value per season	French government (DGAMPA) and Ifremer's fishery information system (SIH). Data treatment by Ifremer (SIH).	For each season, species in each vessel portfolio were ordered following their contribution to the landed value. The number of species that represent 80% of the landed value was used as a measure of vessel specialization (or, inversely, diversification). This simple measure of diversity was chosen over more sophisticated diversity indices for its ease of interpretation and to avoid considering miscellaneous species (not targeted) present in the vessel portfolio due to relative less selective fishing gears.

threshold of 10 tonnes of annual landings of SPF was chosen to select the vessels of our study fleet. All French vessels that reached this threshold at least once during our study period and in our study area were included to the study fleet. This resulted in a fleet of 122 vessels. Within this study fleet, some vessels may have exceeded the threshold only once between 2010 and 2018, while others may have exited the fleet. However, we kept all the vessels to ensure the best overview of what happened in the fleet during the study period. According to expert knowledge and previous studies, there are two main groups in our study fleet, based on the gear used to target SPF (Vermard et al. 2008): purse seiners (33 vessels of our study fleet) and trawlers (89 vessels). These two groups are independent, as vessels geared for seine cannot practice trawling and vice versa. Therefore, we considered these two groups independently in our analyses.

Available data and metrics used

The annual strategy was considered as the summary of the fishing activity deployed by a vessel over a year. From the available fishery data, three aspects were selected to describe it (Table 1): (i) the main métiers practiced (main gear used and main target species) (Ulrich et al. 2012), (ii) the target portfolio described as the contribution of species or group of species to the value of landings (Daurès et al. 2009), and (iii) the diversification versus specialization of the fishing activity (Anderson et al. 2017).

Fishing activity in this fishery is highly seasonal (Supplementary Material S1). Indeed, the market is conditioned by the fat content of SPF, which presents seasonal variations. The fat content is higher during summer, implying strong demand from the canning industry. In accordance with the indications of fishers' representatives, we split the year into two seasons: December to April (hereafter referred to as winter) and May to November (hereafter referred to as summer) and subdivided all metrics accordingly.

Classification overview

The classification we propose follows a two-step clustering analysis (Fig. 2), following the method proposed by Pelletier and Ferraris (2000) and further explored by a number of authors for classification work (Ulrich and Andersen 2004, Daurès et al. 2009, Moore et al. 2019, Schadeberg et al. 2021). First, fishing activity is described annually, then vessels are grouped according to their annual activity.

Fishing strategies and their dynamics

From the annual metrics of vessels (Fig. 2, step 1), we defined strategies (Fig. 2, step 2) following a clustering analysis. The annual metrics were first reduced by Principal Component Analysis (PCA). We kept all axes that, in aggregate, explain 85% of the data variance and performed a Hierarchical Ascendant Clustering (HAC) on the remaining dimensions. This method gives the liberty to choose the final number of clusters according to the needs of each study (Pelletier and Ferraris 2000, Holley and Marchal 2004), the theoretical maximum number of clusters being the total number of individuals in the data. In our case, the number of strategies was chosen as a trade-off between the need to synthetize the seasonal fishing activity and to report on vessel's heterogeneity. The number of strategies (i.e. HAC clusters) was chosen iteratively by computing averages and dispersion of metric values within the clusters. Our objective was to discriminate all strategies relevant in SPF fisheries, in particular each strategy with a specificity concerning seasonal species portfolio. The iteration was stopped when the newly formed clusters reflected unsubstantial differences in the species portfolio or when the differences concerned demersal species catches, which were not the focus of our work.

The resulting set of strategies obtained was then explored to: (i) characterize the diversity of strategies in our fleet, (ii) look for potential associations between strategies and vessel technical characteristics, size, home port, and level of diversi-

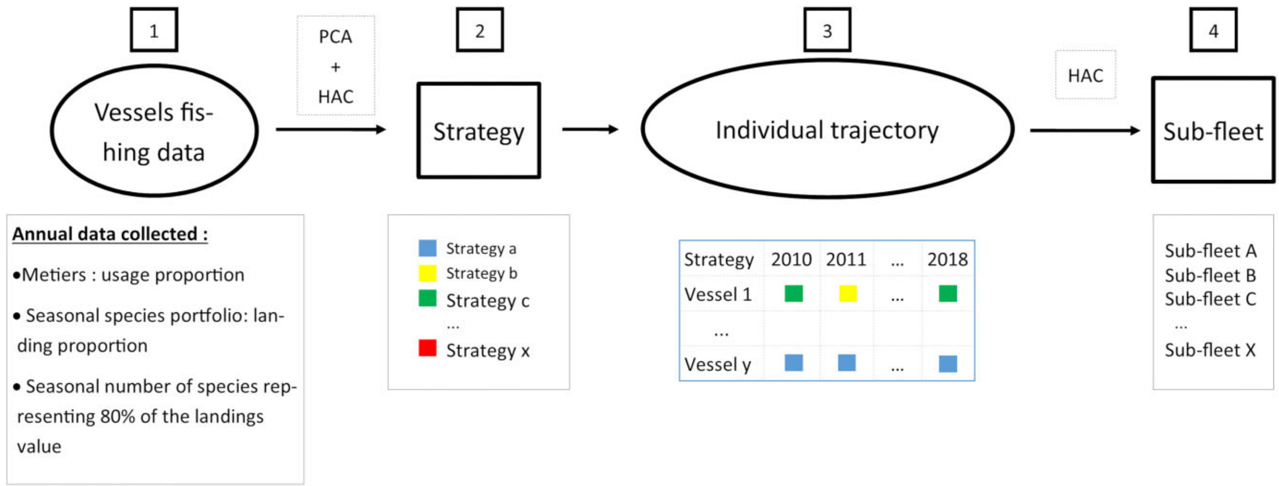

Figure 2. Flowchart of our classification methodology. PCA: Principal Component Analysis. HAC: Hierarchical Ascendant Clustering.

fication (measured as the average number of species targeted per season by vessels participating in the strategy), and (iii) observe the evolution of strategy use over our study period, particularly the emergence or disappearance of strategies over time.

Vessel trajectories

Each vessel in our fleet implemented one specific strategy in each year of our study period. The vessel may have maintained the same strategy throughout the period, changed to another strategy, temporarily exited the pelagic fishery (i.e. fished <10 tonnes of SPF in certain years), or permanently (i.e. ceased any fishing activity). Thus, each vessel had a unique strategy set (Fig. 2, step 3), representing its behaviour during the study period. The vessels that exited the fishery at some point during our study period were kept in the final classification.

To explore these trajectories, we grouped vessels according to the set of strategies they used during our study period. This grouping was performed using a HAC on the proportion of each strategy in vessel's trajectory. The groups of vessels obtained are referred as sub-fleets (Fig. 2, step 4). The final number of sub-fleets was chosen iteratively by looking at individual strategy sequences. The depth of the clustering was chosen to distinguish all representative sets of strategies. We fixed a minimum limit of three vessels for each sub-fleet (in total for all the study period) for representativity and confidentiality considerations.

Based on this new classification, we (i) looked for correspondences between the technical or geographical characteristics of vessels within sub-fleets and (ii) analysed the set of strategies and changes of strategies over time in each sub-fleet to identify opportunities or constraints for adaptation.

Factors underlying fishing behaviours

To better understand fishers' behaviour, and explicit strategic choices, our method proposed to complement the data analysis with a survey conducted with fishers from our study fleet. The purpose of this survey was to list and provide qualitative explanations on the factors that fishers consider when making decisions at different time scales. Interviews were conducted only with skipper-owner fishers. This choice was made because (1) this is the most common ownership structure in French fisheries (Kinds et al. 2021) and (2) a skipper-owner is responsible for strategic decisions at all time scales.

Survey construction

Considering four time scales

Fishers' activity results from a series of decisions made at different time scales. Depending on the time scale, different factors may influence decisions (Andrews et al. 2021). Short-term (usually referred to as fishing tactics) and long-term strategy (Macher et al. 2008) are the two main time scales considered in fishing behaviour studies. We chose to add two other time scales to determine their significance in fishers' strategies: the annual term, the usual time scale to characterize fishing activity, and the seasonal term, as SPF fishery is known to be highly seasonal.

Long-term: the long-term behaviour reflects the fishers' anticipation of changes in the fishery. This scale has been described extensively in the literature and often translated into the entry or exit of a fishery (Salas and Gaertner 2004, Mardle et al. 2006, Vermard et al. 2008, Beaudreau et al. 2019), triggering specific investments and access to fishing rights.

Annual term: the annual scale is the reference scale used to describe the fishery economic performance, as accounting data are collected yearly. In addition, some determinants of the fishing strategy are defined annually, in particular fishing quotas. Considering this, we wanted to determine if fishers have a deliberate strategy at the annual scale.

Seasonal term (less than a year): the factors underlying the decision to start the SPF season could be important to predict fishers' behaviour in this particular fishery. This relates to the triggers of change of activity between seasons (Macher et al. 2008) (e.g. start of the tuna season, end of the sardine season).

Short-term (fishing trip): short-term behaviour is often referred to as fishing tactics (Vermard et al. 2008), and reflects the choices made by fishers for a trip as to what species they will target, with what gear, and in which zone.

Factors underlying fishing strategies

There is an abundant literature about fishers' behavioural drivers and how to implement them in fishery models (van Putten et al. 2012, Girardin et al. 2017, Andrews et al. 2021). A common approach assumes that strategic decisions are driven by profit maximization (van Putten et al. 2012). This framework assumes that fishers primarily consider economic fac-

Table 2. List of the factors expected to drive fishers' behaviour classified in five categories.

Group	Factor	Description	Expected temporal scale	Expected
Socio-personal	Tradition/habit	Decisions based on personal or social tradition.	Long-term	Yes
	Other vessel strategy	Decisions based on information shared by other vessels.	Short-term	Yes
	Fishing method	Attractiveness of the fishing method.	Long-term	No
Resource	Quality	Resource quality fluctuations during the year.	Seasonal	Yes
	Availability	Resource availability fluctuations in space and time.	Short-term, seasonal, annual	Yes
Regulation	Quotas	Annual limits imposed by quotas.	Annual, seasonal	Yes
	Producer organization rules	Regulation imposed by producer organizations.	Annual, seasonal, short-term	Yes
	Fishing rights	Specific fishing right needed for a species and/or gear.	Long-term	Yes
Environment	Weather	Weather constraints limiting gear or access to fishing grounds.	Short-term	Yes
	Fishing grounds	Fishing grounds constraints for gear operation.	Short-term	Yes
Economy	Revenues	Maximization of the expected revenues.	Short-term, seasonal	Yes
	Contracts	Contracts made with buyers	Seasonal, short-term	Yes
	Investments	Investments needed to adopt a strategy.	Long-term	Yes
	Costs	Costs minimization.	Short-term	Yes

tors (expected revenues and associated costs) (Macher et al. 2008, Simons et al. 2015). Expected revenues rely on resource availability and quality, as well as their value on the market (Haynie and Pfeiffer 2012). In data-rich fisheries, revenues and costs are directly available or can at least be approximated (van Putten et al. 2012). However, other studies highlighted that fishers' behaviour is more complex, and that other factors are important to consider (Holland and Sutinen 2000). In particular, the social and personal context must be considered, with factors such as tradition (Vermard et al. 2008), information flow (Turner et al. 2020), cooperation with other fishers (Salas and Gaertner 2004, Bailey et al. 2010, Murray and Ings 2015), or fishers' personality (Christensen and Raakj 2006). We also had to consider the constraints that limit fishers' decisions. First, fishers' decisions are constrained by numerous regulations (Girardin et al. 2017). These regulations can be static (e.g. an area closure) or can be variable (e.g. fishing quotas). Second, fishers' decisions are limited by environmental constraints. In a way similar to regulations, environmental constraints can be static (e.g. a bottom trawler cannot fish in a rocky zone) or fluctuating (e.g. the weather). We expected these constraints to impact decisions at different time scales.

The factors collected in the literature were classified into five categories: economic factors, resource-related factors, social and personal factors, regulatory factors, and environmental factors (Table 2). For each factor, the relevant time scale is indicated. For instance, weather conditions were expected to be relevant for the short-term strategy, and quotas for the annual strategy (with the total amount of catch allowed) and the seasonal strategy (with the speed of consumption during the year). To improve results' clarity, Table 2 also indicates whether or not a factor was anticipated by the research team prior to the interviews.

Survey implementation

A semi-structured questionnaire was favoured to allow fishers to freely express themselves and to avoid influencing their responses (see Supplementary Material S2). For each time scale, the respondent was asked which factors were considered when making fishing decisions. The order of appearance of the factors in the response was considered representative of their importance and recorded. Additional information on the reasons why a factor was important or how it was used in decision-making was also recorded. Complementary information was collected during the interview to be used qualitatively, related to socio-demographic characteristics, personal history, and the respondent's vision of the future of the small pelagic fisheries. Specific questions were asked regarding their membership in a PO and their opinion about the PO's action in the fishery.

Sampling

Our sampling was based on the classification obtained in the first step of our study. Initially, our goal was to sample all the sub-fleets identified. However, the survey took place during the COVID pandemic in 2020, which limited our ability to meet fishers. It was therefore decided to focus only on the sub-fleets targeting mainly sardine which was the species of concern in the fishery at the time. To investigate contrasts between purse seiners and trawlers, we interviewed skippers from one purse seine and two comparable trawler sub-fleets.

Fishers' representatives helped us to contact skippers we had previously identified in our data. They were surveyed on a voluntary basis without compensation. Appointments were either arranged in advance or opportunistically organized when visiting the boat owner on the deck when returning from trips. Interviews were designed to last a minimum of 20 minutes. Preference was given to face-to-face interviews, but some were conducted by phone due to COVID-19 restrictions.

Results

Historical perspective and fleet classification

The PCA on fishing activity metrics explaining 85% of the variance represented 10 dimensions for the trawler group and 5 dimensions for the purse seine group. The construction of fishers' strategies resulted in 16 strategies, 11 for the trawler group (strategies a to k) and 5 for the purse seine group (strategies m to q). Figures 3 and 4 display the HAC dendrograms and seasonal species landing proportions for, respectively, trawler strategies and purse seine strategies. Although the seasonal species landing proportions are only one of the

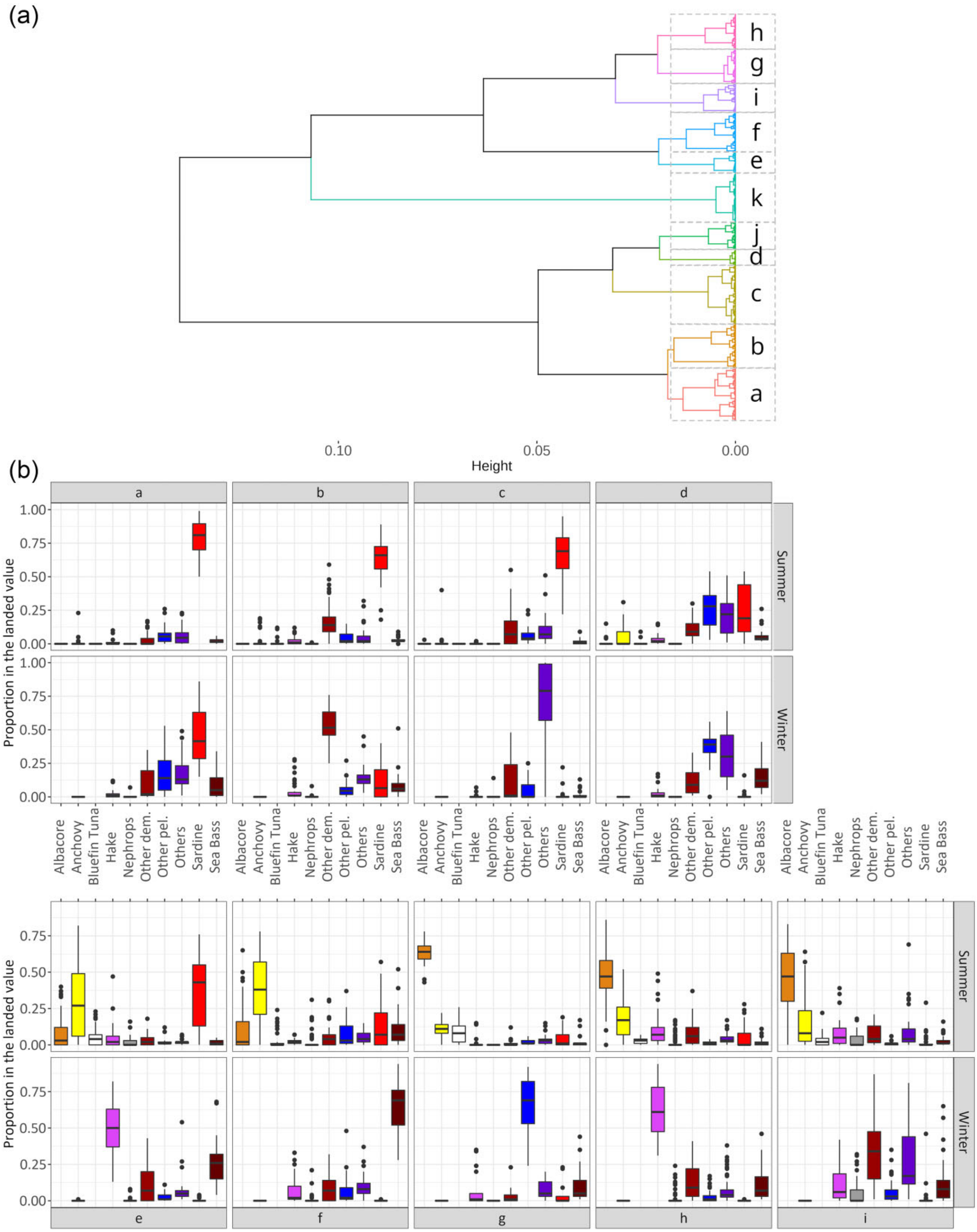

Figure 3. Strategies practiced by trawlers over the period 2010–2018. (a) clustering dendrogram. (b) Seasonal species portfolio of each strategy representing the share in the landed value of each species or group of species included in the PCA. See Table 3 for details on the strategies.

three metrics used in the clustering, they best illustrate the differences between strategies to understand their specificity. Other metrics, as well as key information about strategies are summarized in Table 3.

The main result was the importance of seasonality to distinguish between strategies and the strong correlation between the strategy used and home harbour (see Fig. 1 for harbour locations) and vessel size. Based on the clustering, three strate-

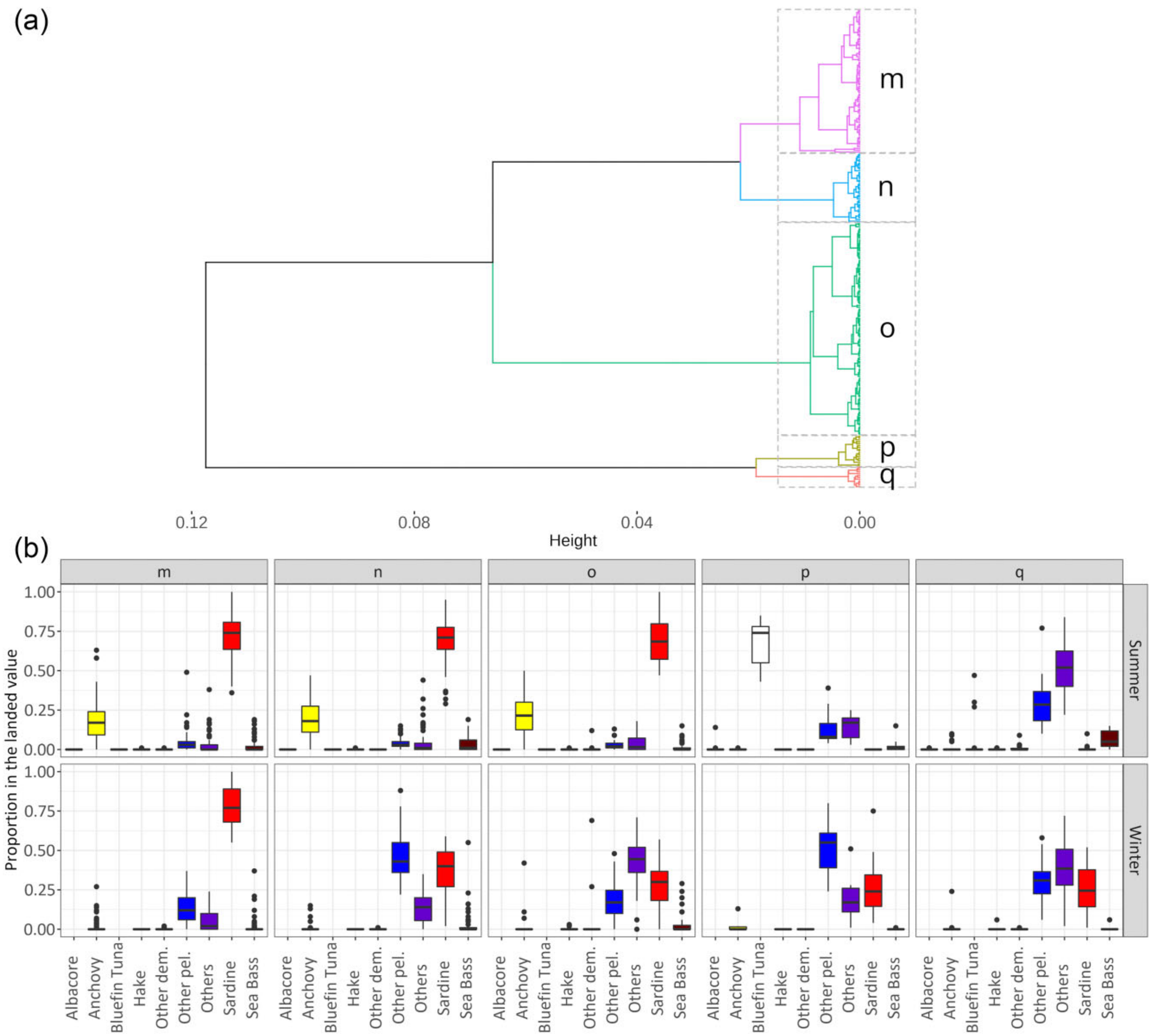

Figure 4. Strategies practiced by purse seiners over the period 2010–2018. (a) clustering dendrogram. (b) Seasonal species portfolio of each strategy representing the share in the landed value of each species or group of species included in the PCA. See Table 3 for details on the strategies.

gies were identified as specialized in sardine, either all year long (a) or during summer (b and c), and are practiced by boats of 10–12 m originating from Saint-Gilles-Croix-de-Vie (a and c) or Quiberon (b). The small vessels (10–12 m) from La Turballe (d), on the other hand, were more diversified (3 to 5 species depending on the season). This polyvalence explains their proximity to strategy j in the classification tree, which is used by polyvalent bottom trawlers. Four strategies (e, f, h, and i) were distinguished for the larger vessels (18–24 m) from La Turballe, all targeting a specific combination of pelagic species in the summer (anchovy, sardine, or tuna) and demersal species in winter (hake, sea bass, or other demersal species). Large vessels (18–24 m) from the southernmost harbours target tuna in summer and other pelagic species in winter (g).

In the purse seine group, the strategies were primarily defined by the share of SPF in the value of landings. It clearly distinguished the three strategies (m, n, and o) that targeted almost exclusively SPF (sardine, anchovy, and other small pelagic fishes) from strategies p and q mainly targeting other species (seabass, tuna, and seabream). This distinction was related with origin harbours of vessels, with strategies m, n, and o implemented by vessels from Brittany (Saint-Guénolé and Douarnenez harbours, see Fig. 1). Subdivisions between strategies m, n, and o were linked to the SPF species targeted in winter. Subdivision between strategies p and q was linked to the high share of Bluefin Tuna in strategy p's landed value.

Evolution of the fishery tracked by strategies

In 2018, the dominant strategies were strategy m (33% of vessels) for purse seiners and strategies I (25%), h, e, and a (15% each) for trawlers. However, Fig. 5 shows that the dominant strategies changed between 2010 and 2018. Some strategies developed while others declined. The number of vessels involved in the SPF fishery also evolved (Fig. 5).

The trawler subgroup had several notable evolutions in the use of strategies. Chronologically, the first evolution was the sharp decrease of strategy f targeting seabass and anchovy between 2010 and 2013 before stabilizing at a low level until

Table 3. Trawlers and purse seiners strategies.

	Summer		Winter		Vessel characteristics				
Code	Main species targeted (mean contribution to landings value)	Mean nb species contributing to 80% of the landings value	Main species targeted (mean contribution to landings value)	Mean nb species contributing to 80% of the landings value)	Main gear	Main harbour (% of vessels from the harbour)	Main class length (% of vessels in the class length)	Nb of vessels∗years that used the strategy (2010–2018)	Nb of vessels that used the strategy in 2018
Strategy—Trawlers									
a	*Sardine* (80%)	1.3	*Sardine* (45%)	2.8	Pelagic trawl	Saint-Gilles-Croix-de-Vie (61%)	10–12 m (52%)	46	7
b	*Sardine* (64%)	1.5	Others (74%)	1.8	Pelagic trawl and dredges	Quiberon (Port-Maria) (62%)	10–12 m (92%)	26	3
c	*Sardine* (62%)	2	Other demersals (51%)	4.8	Mixed trawl	Saint-Gilles-Croix-de-Vie (50%)	10–12 m (50%)	46	3
d	Other pelagics (34%)	5.4	Other pelagics (40%)	3.7	Pelagic trawl	La Turballe (57%)	10–12 m (81%)	21	1
e	*Sardine* (39%)	1.8	*Hake* (48%)	2.2	Pelagic trawl	La Turballe (62%)	18–24 m (97%)	37	6
f	*Anchovy* (36%)	2.7	*Sea Bass* (64%)	1.9	Pelagic trawl	La Turballe (52%)	18–24 m (52%)	50	2
g	*Albacore* (63%)	1.7	Other pelagics (64%)	1.6	Pelagic trawl	Saint-Jean-de-Luz, Ciboure (57%)	18–24 m (100%)	21	1
h	*Albacore* (48%)	2.6	*Hake* (63%)	2	Pelagic trawl	La Turballe (70%)	18–24 m (86%)	72	6
i	*Albacore* (45%)	2.5	Other demersals (35%)	4.6	Mixed trawl	La Turballe (68%)	18–24 m (82%)	44	12
j	Other demersals (28%)	5.9	Other demersals (49%)	6.9	Bottom trawl	La Turballe (40%)	12–18 m (58%)	45	3
k	*Nephrops* (52%)	3.1	*Nephrops* (48%)	3.7	Bottom trawl	Lorient (95%)	12–18 m (85%)	55	3
Strategy—Purse Seiners									
m	*Sardine* (72%)	1.1	*Sardine* (77%)	1.1	Purse seine	Douarnenez (41%)	12–18 m (96%)	111	20
n	*Sardine* (71%)	1.1	Others (43%)	2.3	Purse seine	Douarnenez (40%)	12–18 m (90%)	42	0
o	*Sardine* (68%)	1.1	Others pelagics (47%)	2.3	Purse seine	Saint-Guénolé (Penmarch) (58%)	12–18 m (97%)	74	6
p	*Bluefin Tuna* (67%)	3.2	Others pelagics (51%)	2.4	Purse seine	Saint-Jean-de-Luz, Ciboure (64%)	18–24 m (55%)	11	2
q	Others (52%)	1.5	Others (40%)	2.5	Purse seine	Saint-Jean-de-Luz, Ciboure (100%)	10–12 m (61%)	18	2

We indicated, by season, the main species or group of species targeted, its mean proportion in the value of landings, and the mean number of species corresponding to 80% of the landing values (specialization metric). Mean values are computed from individual values of individuals that used the strategy. Species are designated by their common name; see Table 1 for correspondent scientific names. The main characteristics of vessels are also summarized with the corresponding proportion of vessels: main harbour and main class length (see Supplementary Material for harbour locations). The number of vessel∗year corresponds to the number of individuals (i.e. vessels that used the strategy multiplied by the number of year they used it) in the group, the number of vessels that used this strategy in 2018 is indicated

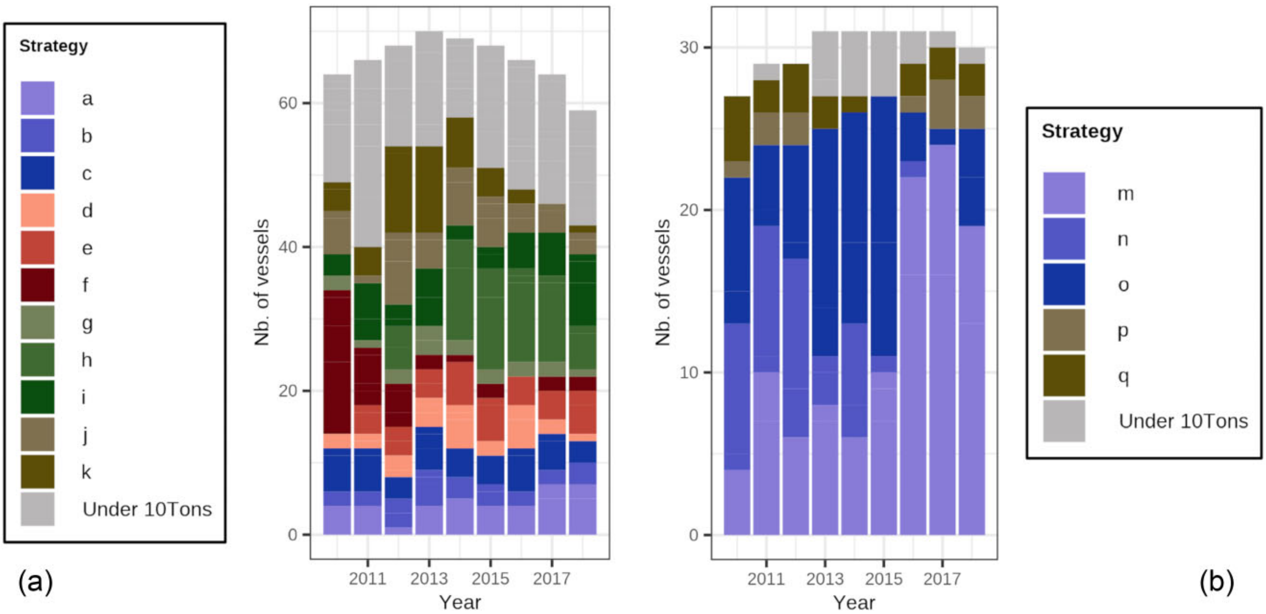

Figure 5. Evolution of strategy usage in (a) trawler and (b) purse seiner subgroups. Strategies sharing the same colour (i.e. blues, reds, greens, etc.) have similarities. Blue strategies (a to c) target mainly sardine, reds (d to e) various pelagics, greens (g to i) target albacore, and browns (j and k) target demersal species.

2018. On the contrary, demersal strategies j and k increased in 2012 and decreased subsequently. From 2010 to 2018, the use of strategies targeting albacore (strategies g, h, and i) increased. The relative proportion of these strategies changed. Strategy g remained at a low level, while strategy h was largely dominant between 2014 and 2017. Strategy i increased between 2016 and 2018. Strategies targeting sardine (a, b, and c) remained at relatively constant levels during the study period.

The total number of vessels included in the trawler subgroup along our study period decreased globally, with 56 vessels in 2010 and 47 in 2018. There were two extreme years, with a minimum of 41 vessels in 2011 and a maximum of 62 in 2014.

In the purse seine subgroup, there was a clear evolution towards a strategy targeting sardines all year long (strategy m), with an increase in vessels practicing this strategy from 14% in 2010 to 67% in 2018 (with a peak at 80% in 2017). This strategy replaced strategy n (after 2014) and then strategy o (after 2015), which were targeting a wider variety of species during winter. The cumulative percentage of strategies n and o used fell from 69% in 2010 to 20% in 2018. This seemed to indicate an evolution of Brittany's purse seiners towards a specialization in sardine fishing. Strategies p and q were practiced by a small number of vessels. These strategies decreased and even disappeared between 2013 and 2015. The overall number of vessels was constant in the purse seine subgroup.

Individual trajectories and adaptability

This step built our final classification by grouping vessels that used a similar set of strategies. Figues 6 and 7 show the 11 trawler sub-fleets and the 3 purse-seine sub-fleets, respectively. For each sub-fleet, mean length of vessels and main port of origin are indicated. Note that the variations of the vessels' number in a sub-fleet are caused either by the entry/exit of vessels of our study fleet or by transfers of vessels between sub-fleets. Such transfers are possible when a vessel changes ownership. A new individual is then created and assigned to a possibly different sub-fleet.

The trawler group was complex, as it was composed of numerous vessels and numerous identified strategies. However, the vessels were remarkably specialized, which modifies the global vision drawn in the previous section. Nine sub-fleets had between 3 and 8 active vessels per year. Sub-fleets B2 and E1 were more numerous with a peak at, respectively, 14 and 12 active vessels. Seven of the sub-fleets virtually used a unique SPF strategy over the study period (A1, A2, A3, C1, C2, E1, and E2). In addition, there were few overlaps between fleets with regard to strategies used. Most strategies were structuring for one sub-fleet only (e.g. strategy a for sub-fleet A1 or strategy g for sub-fleet C1). Therefore, despite the diversity of strategies identified for trawlers, each vessel displayed limited choices. This revealed underlying constraints that limited individual adaptability. To facilitate the interpretation, sub-fleets with common characteristics are analysed together in the following discussion.

Sub-fleets A1, A2, and A3 mainly used sardine-oriented strategies (respectively a, c, and b). With few exceptions, the same strategy was used over our study period. It should be noted that some vessels of sub-fleet A2 switched to strategy a after 2015, revealing a highest share of sardine landing in winter. Vessels of sub-fleets A1 and A2 originated from the central part of the BoB (Saint-Gilles-Croix-de-Vie and Les Sables d'Olonnes harbours), while vessels from A3 originated from northern harbours (Quiberon and La Turballe). Vessels from these 3 sub-fleet are mainly <18 metres long, with A3 entirely composed of vessels <12 metres long.

Vessels from sub-fleets B1, B2, and B3 had in common the use of strategy f (targeting sea bass in winter) in the early years of our study period. B1 vessels kept using strategy f all along the period. While B2 and B3 abandoned this strategy in 2012–2013 and switched to strategies g (tuna) and e (hake), respectively. The vessels of the 3 sub-fleets originated from harbours in the central part of the BoB. However, vessels from B1 were

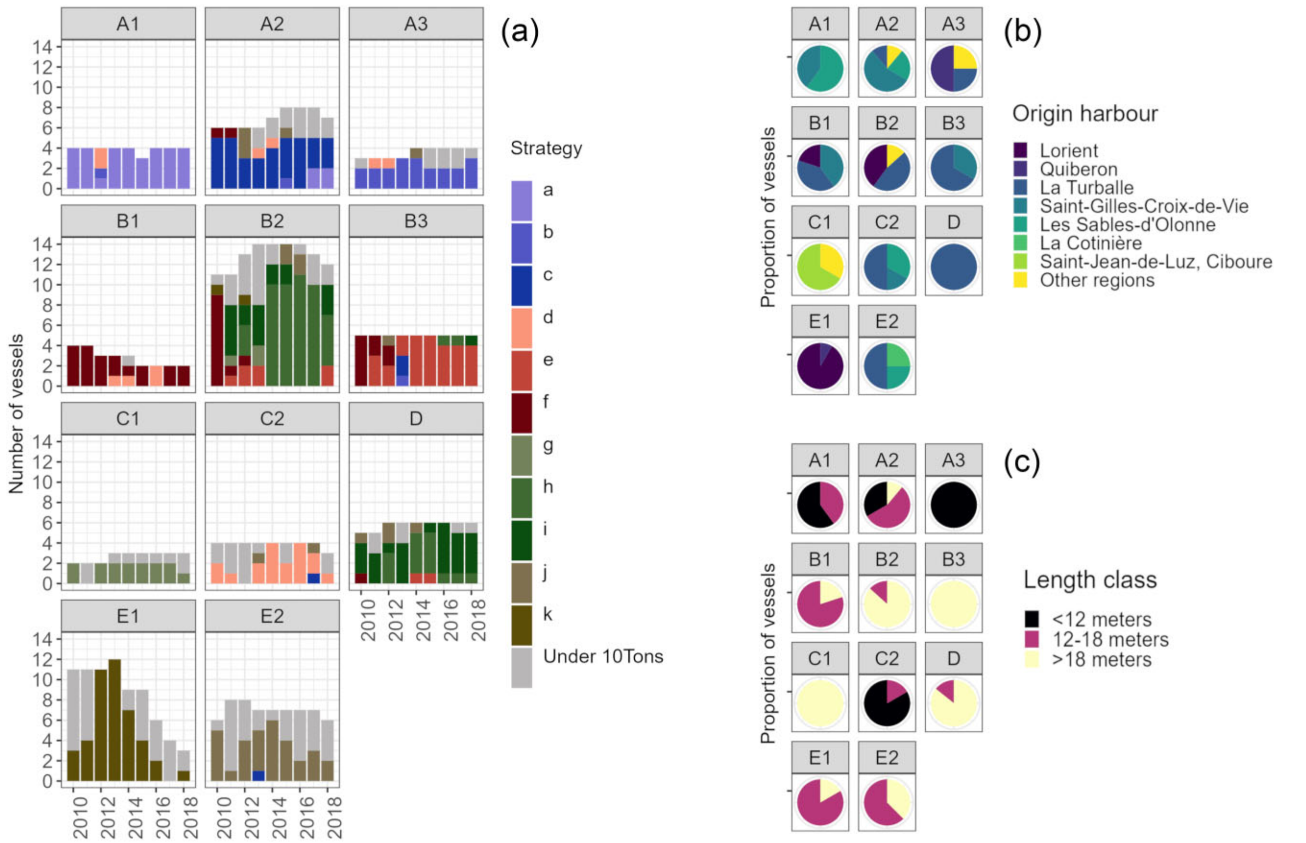

Figure 6. (a) Classification of the trawlers group and strategic evolution inside each sub-fleet. Each panel is a sub-fleet and the bars indicate the overall number of vessels each year (x-axis) as well as the proportion of vessels using each strategy (colours) or having fished less than 10T of pelagics. Sub-fleets with the same capital letter in their denomination have characteristics in common. (b) Origin harbour of vessels (from North to South). (c) Length class of vessels.

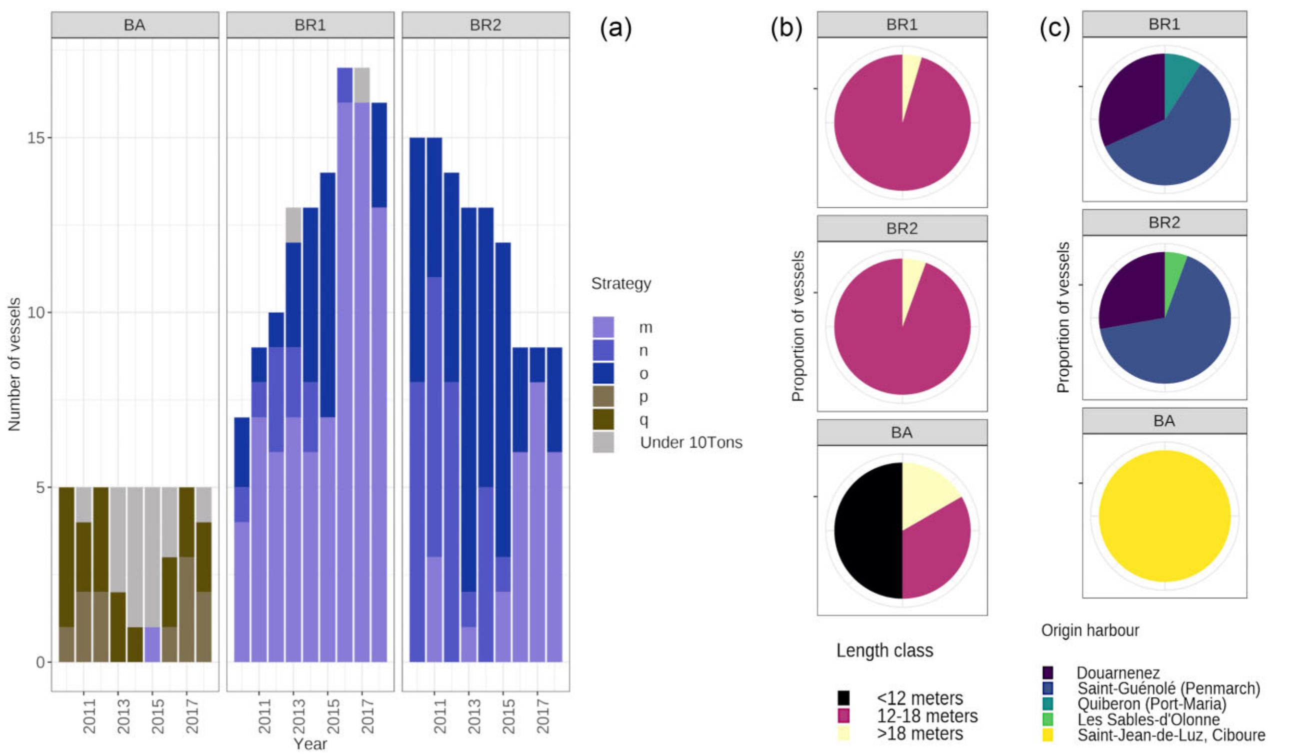

Figure 7. (a) Classification of the purse seiners group and evolution of the strategy used inside each sub-fleet. Each panel is a sub-fleet and the bars indicate the overall number of vessels each year (y-axis) as well as the proportion of vessels using each strategy (colours) or having fished less than 10T of pelagic fish. (b) Origin harbour of vessels (from North to South). (c) Length class of vessels.

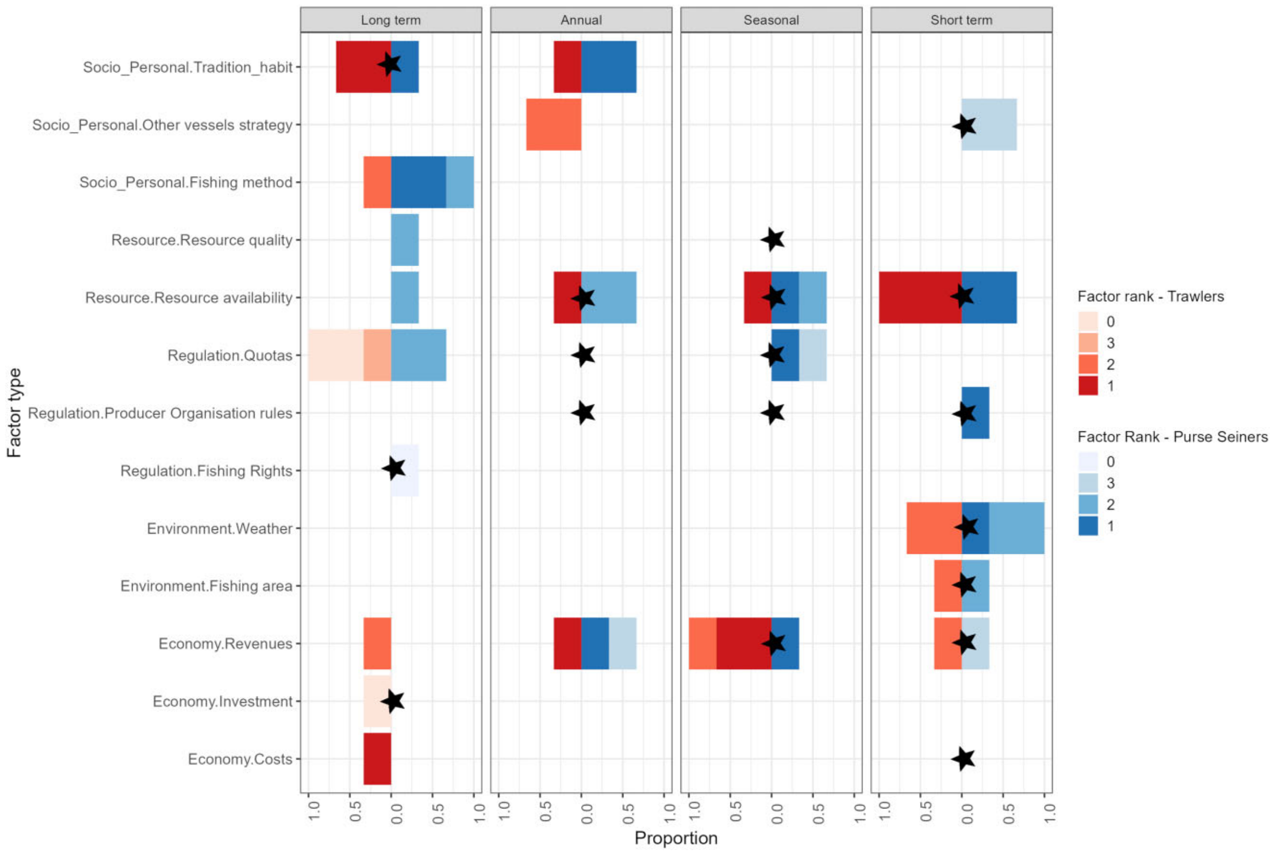

Figure 8. Factors considered by fishers surveyed to build their fishing strategy at four different time scales. Purse seines' answers are indicated in blue, trawlers' in red. Colour shades indicate the rank of the factor in the respondent's answers, from the first factor mentioned (1) to the last (3). Factors '0' were mentioned by the fisher as unimportant. Factors marked with a black star were those expected prior to the survey for each time scale (see Table 2). Five groups of factors were identified: socio/personal, resource-related, regulation, environmental, and economic.

smaller (12 to 18 metres long) compared to vessels from B2 and B3 (>18 metres).

C1 and C2 vessels used strategies targeting pelagic fishes other than sardine or anchovy. They almost exclusively used the same strategy over the period (respectively g and d). Vessels from C1, targeting tuna, originated from Saint-Jean-de-Luz and were >18 metres. Sub-fleet C2 represented the smallest vessels from harbours in the central part of the BoB.

Sub-fleet D was composed of vessels that alternated between strategies h and i. The two strategies targeted albacore in summer but differed in winter landings by the relative level of hake compared with other demersal fishes. Nevertheless, vessels seemed to be able to switch between them depending on the year. This sub-fleet is close to sub-fleet B2 but vessels did not use strategy f in the beginning of the period. Vessels from this sub-fleet originated from La Turballe and were >18 metres long.

Finally, sub-fleets E1 and E2 used strategies k and i almost exclusively, that is to say targeting demersal species. E1 vessels mainly targeted Nephrops, while E2 vessels targeted other demersal fishes. The proportion of vessels landing <10 tonnes of SPF per year is consistently high. However, different patterns can be noted. In E1, the number of vessels landing <10 tonnes of SPF dropped in 2012–2013 while there was no clear pattern in E2, though possibly a decrease since 2015. Vessels from E1 were mainly 12 to 18 metres long and originated from Lorient. Vessels from E2 originated from Les Sables d'Olonnes.

The purse seine group was divided into three sub-fleets and revealed a clear geographic distinction. The main ports of origin of vessels from sub-fleet BA were located in the Basque country (Saint-Jean-de-Luz and Cibourre), while vessels of BR1 and BR2 were located in Brittany (Douarnenez and Saint-Guénolé). Vessels from the Basque country exclusively used strategies p and q, which were not sardine-oriented strategies (see Table 3). On the contrary, vessels from Brittany (BR1 and BR2) used sardine-oriented strategies m, n, and o. The distinction between BR1 and BR2 was based on the dominance of strategy m in BR1. Vessels in BR2 were more likely to use strategies n and o, reflecting a more diversified variety of species landed during winter. This distinction tended to disappear towards the end of the study period, as vessels from BR2 adopted strategy m. Plus, the overall number of vessels of BR1 increased, while it decreased for BR2, indicating that vessels entering BR1 were mainly drawn from BR2.

Factors underlying fishers' strategic choices

Three skippers from sub-fleet BR2 (purse seine group) and three skippers from fleets A1 and A2 (trawler group) were interviewed. Due to the small number of fishers interviewed, we chose to group vessels from the two trawler sub-fleets (A1 and A2). These two sub-fleets have many common characteristics and vessels that originate from the same harbour. As a reminder, A1 targets sardine all year long, while A2 targets sardine in summer then demersal fishes in winter. The 6 respondents were also experienced fishers, aged between 40 and 54 years. In 2018, there were 9 vessels active in the purse seine sub-fleet BR2 and 9 vessels in total in the trawler sub-fleets A1 and A2 (see Figs 6 and 7). Thus, our sampling represented 33% of each of these groups.

Different factors and time scales

First, our survey confirmed that fishers make decisions at various time scales and they easily explained the type of factors considered at each scale (Fig. 8). It also confirmed the assumption that fishers rely on different factors to make decisions depending on the time scale. Finally, there was a good consensus between respondents from a given fleet at the long- and short-term scales.

Long-term decisions were understood as the choice to stay in the fishery and keep the same gear. It was often recognized as being driven by personal and social factors, but responses differed between purse seiners and trawlers. In their choice of practicing purse seine, the three purse seine skippers mentioned the attractiveness for this particular fishing method as the first or second factor. Purse seine fishing was seen as a 'hunt', looking for schools of fish. The interesting pace of work was also mentioned. In contrast, 2 out of 3 trawler skippers in the trawler group chose this type of fishing due to a family or community tradition.

Factors determining short-term decisions were those influencing the choice to go out to sea and of a target species or fishing ground. These were similar across fleets. Resource availability (i.e. what species are available in their fishing area) was the main factor considered. Weather was often quoted as the second or third factor considered. In addition, fishers mentioned weather to be more decisive in winter in the choice of the fishing area.

There was more individual variability in the responses regarding seasonal and annual activity. In terms of seasonal decisions, expected revenues (demand from large buyers and related price increases) were unanimously mentioned by trawlers. It should be noted that the increasing demand from large buyers (canneries) is generally motivated by the fat content of the resource (or resource quality), which can create confusion between these two factors during the interviews. In addition, purse seiners mentioned quotas and resource availability.

The annual scale was less well understood and seen as the result of seasonal choices rather than planned beforehand. This explains why the factors are largely similar at the annual and seasonal scales. However, at the annual scale, fishers mentioned personal habits to reflect the fact that they try to stick to their usual seasonal pattern unless conditions force them to change it.

Fishers expressed different levels of control or decision-making power over their activity at the different time scales. Short-term and long-term decisions are subject to conscious choices, while seasonal and annual decisions are primarily dictated by external constraints (the cyclical calendar of species and the industry's strategy, as reflected by the market opportunities).

Theoretical expectations versus fishers' perceptions

The factors evidenced in the survey results were different from what was expected from the literature review. In particular, different studies stressed that fishers are not only driven by profit maximization (Salas and Gaertner 2004, van Putten et al. 2012, Murray and Ings 2015). Nevertheless, we expected economy-related factors to be more prominent in fishers' responses. For long-term decisions, the economic viability of the fishery or the investments required were not mentioned or were mentioned as unimportant. Fishers' choices were more driven by personal factors. Likewise, economic aspects such as market exploitation possibilities or previous results on a given fishing ground were not predominant in short-term decisions, as is often suggested in the literature (Macher et al. 2008). Instead, fishers mentioned day-to-day resource availability (understood as schools' location) as the main factor. SPF schools' locations are highly variable and not entirely predictable through personal experience. Nevertheless, market demand is considered unanimously important at the seasonal and annual time scales.

The low importance given to regulatory factors was also surprising. These factors were expected to be important at different time scales. Fishing rights for the long-term decisions, quotas for annual or seasonal decisions, and PO rules for short-term, seasonal, and annual decisions. Quota fluctuations, in particular, were not considered by our respondents to influence their decisions. According to them, this is due to the specific quota context of these sardine-oriented sub-fleets. Indeed, sardines, their main target, are not subject to quotas. For other small pelagic species, quotas are either non-limiting (anchovy) or so limiting that the species concerned are not included in any strategy planning (horse mackerel, mackerel) but rather fished opportunistically. When probed about fishing rights, one respondent replied that they are not relevant while making long-term decisions as they come with the boat. During our survey, purse seiners explained that POs play an important role in regulating the daily quantity of sardines landed during winter, when the demand is low. However, only one respondent mentioned PO rules as a significant factor in short-term decisions.

Discussion

Contribution of a strategy-based classification

Classifications are mainly based on the fishing activity over a given period of time (often a year) (Fonseca 2008, Hamon 2009, Meyer 2021) and give a picture of a fleet at a given time. In French fisheries, the limitations of these classifications have been highlighted due to the complexity and diversity of fishing activity and alternatives have been proposed (Daurès et al. 2009, Deporte et al. 2012). Our classification differs in two aspects. First, the fine scale at which it considers fishing activity by detailing seasons, and second, the consideration of the dynamics of the fishing activity over almost a decade.

By considering the seasonality of fishing activity, we revealed that vessels can have a similar activity in summer while different in winter. Purse seiners from Brittany, for example, can either use a strategy focused on sardine during winter or diversify the species targeted. Likewise, trawler strategies targeting sardine in summer differ by the species they will target in winter. We also found evidence that seiners expanded the sardine season over the winter beyond the traditional summer months.

Second, from the individual data of vessels, our method was constructed to highlight the dynamics of the individual activity and identify historical patterns leading to an innovative classification. Unlike most existing fleet classifications, we chose to assign a unique fleet to each vessel and instead use strategies to reflect annual changes. This stability with respect to fleet composition of vessels in a fleet, is closer to the perception and actual inertia of the sector due to habits, the irreversibility of investments, and regulations (Demaneche et al. 2022). To help quantitative analyses achieve greater stability in vessel assignment, the same authors advocated for the use of pre-segmentations, e.g. based on objective factors such as the combination of gears used or the area of practice, before applying quantitative analyses. We further believe that pre-segmentation based on qualitative knowledge, common sense, or expert knowledge (e.g. PO membership), should be exploited to avoid known biases of cluster analysis (such as emphasis on original individuals). In our case, the consideration of individual trajectories over several years implicitly grouped vessels according to characteristics that may not have been recorded.

The choice of the clustering method has a significant impact on the final results. Our case study falls within a reliable application scope of PCA + HAC, as all the metrics we used were continuous and normalized. The method has also been widely used in fleet typology studies (Pelletier and Ferraris 2000, Ulrich and Andersen 2004, Daurès et al. 2009, Moore et al. 2019) and tested in a comparative study (along CLARA and k-means methods) by Deporte et al. (2012), proving the reliability of the results.

Although the method we used is not directly designed to reveal time patterns, our classification revealed underlying consistent time adaptation patterns among fishers. In another case study, the use of a time series method may be necessary when forming sub-fleets. The use of some strategies drastically decreased (purse seine strategies n and o, trawler strategy f) while it increased for other strategies (purse seine strategy m, trawler strategies i and h). Moreover, grouping vessels by strategy trajectories revealed their limited choice in strategy and adaptation. Most sub-fleets were defined by a unique strategy and displayed limited choices of adaptation when changing strategy.

The history of sub-fleets B1, B2, and B3 is a revealing example. In the early 2010s, sea bass resources slumped in the English Channel and, to a lesser extent, in the BoB. Limiting quotas had been adopted in the BoB since 2012, and emergency measures were taken for the English Channel area (López et al. 2015). This context can explain the collapse of strategy f (which targeted sea bass in winter) in 2012 and 2013. During this period, B2 and B3 abandoned strategy f at the same time while B1 kept using it. Here, our study revealed that some vessels have adapted to a changing context by switching strategy while others kept a seemingly less viable strategy. Our study also revealed that over 16 vessels that used strategy f in 2010 then abandoned it, 14 adopted strategies targeting hake in winter but in combination with SPF (B2) for a part of them, and with albacore tuna for the rest (B1). The reason for this difference remains unclear, as the characteristics (mean length and port of origin) of vessels from B2 and B3 are similar. Fishing rights (quota, license) could be an explanation. Unfortunately, our constraints did not allow us to interview fishers from these sub-fleets, although it would have been an efficient way to gain complementary insights on this topic.

Globally, trajectories also revealed the increasing dependency of the pelagic fleets on sardine, either by replacing a target species with sardine (example of strategies a and e for trawlers), or by extending the sardine season (use of strategy m instead of o for seiners from Brittany).

By showing vessels fishing <10 tonnes of SPF, our classification also suggested that some vessels targeted SPF opportunistically. Two kinds of behaviour were observed: one ‘grouped’ behaviour and one ‘isolated’ behaviour. ‘Grouped’ behaviour is revealed by an orderly pattern of vessels fishing more/<10 tonnes of SPF. Sub-fleets E1 in the trawlers group and BA in the purse seiners group showed such an orderly pattern (although opposite). The E1 proportion of vessels landing >10 tonnes of SPF increased from 2010 to 2013 and decreased afterwards. In BA, this proportion decreased until 2015, then increased again. Such behaviour may indicate that vessels have collectively responded to a modification in the fishery context. It could be a direct effect of SPF, i.e. better exploitation of SPF in a given period, or an indirect effect, i.e. a decrease in fishing opportunities related to other species that led to a shift of fishing effort to SPF.

On the other hand, other sub-fleets showed a proportion of vessels landing >10 tonnes of SPF that did not follow a pattern. This was the case of sub-fleets B2, D, C2, and E2. Such behaviour may reflect that fishers targeted SPF following personal considerations and choices.

This classification work provides a good overview of the dynamics of fishing activity and reveals the choices made by fishers. However, this method is highly dependent on the time period used as a reference and the segmentation could be challenged if the method were applied with additional years. Instead, the classification has been successfully expanded outside the study period (2000–2009 and 2019–2021) by projecting new individuals (vessel-year) on the PCA plane and identifying the strategy used in the new year among the existing ones (see Supplementary Material S3). This assumes that the strategies remain close to those used during the reference period and could prevent the detection of a drastic change in behaviour. Therefore, this classification is not designed to replace a normative classification that could be used in a regulatory framework. However, it revealed criteria, such as length class or origin of vessels, as well as affiliation with a given PO, that can be used in a stable classification, independent from time-variable considerations.

Data analysis and fishers’ experience conversation

In line with previous work (Hind 2015, Schadeberg et al. 2021, Kraan et al. 2023), our study attempted to use fishery data analysis and fishers’ knowledge jointly. Fishery data analysis highlighted evolutions in fishers’ strategies without explicitly providing access to the underlying reasons.

To this end, fishers’ knowledge proved to be complementary to our data analysis on a seasonal and annual scale. For instance, the BR2 purse seine sub-fleet investigated in our survey had specialized in sardine between 2010 and 2018. This specialization is visible in fishery data. However, several reasons could explain this specialization. Sardine may have become more profitable over the years, so fishers may choose to specialize to increase their efficiency (Anderson et al. 2017), or this specialization may reflect a loss of other fishing opportunities. The fishers surveyed in our study allowed us to conclude that the latter was the driving factor.

Our interviews underlined the predominance of socio-personal factors regarding long-term choices. Keeping the example of the BR2 sub-fleet, fishers showed their attachment to the métier, which they perceived as stimulating and with a good working rhythm. Even in an unfavourable economic context, these factors are strong incentives for fishers to choose this métier. These factors are difficult to capture through fishery data analysis. Here, fishers experience is valuable to highlight their importance. Implementing them as major drivers in behavioural models may help anticipate fishers' adaptation (Andrews et al. 2021, Restrepo-Gómez et al. 2022).

The results of our interviews regarding short-term drivers were more consistent with previous work modelling fishers behaviour (Vermard et al. 2008, Girardin et al. 2015). It can mainly be summarized as the choice of fishing ground. It was first driven by the location of the fish and secondly by environmental factors limiting the ability to travel to the fishing grounds (weather and distance of the fishing area from the coast). However, our interviews did not allow to weigh the different factors leading to knowledge of where the fish were located or, in particular, the relative importance of personal experience, the success of previous trips, or the information flow between fishers.

There are limitations to our work that did not allow us to fully exploit and validate fishers' knowledge in combination with the data analysis. Due to time constraints and the context of the pandemic, we were able to interview only a limited number of fishers from mainly two sub-fleets. The results should therefore be considered with caution regarding their generality within and across fleets. Moreover, we were not able to ask for fishers' explanations on most of the strategic adaptations evidenced by the quantitative work. For instance, we traced the evolution of the sub-fleet initially targeting sea bass during winter until restrictions on the métier in 2015. It remains unclear why some vessels switched to a strategy targeting albacore and hake while others chose a strategy targeting SPF and hake despite the mean length and main harbour of the vessels being the same.

A unanticipated limit of our interview design was that the decision factors depended on métier or species. Indeed, each species had its own constraints (quota for horse mackerel and the availability of big fish for sardine), and the recorded response used in the quantitative treatment of the responses probably depended on what species the fisher had in mind when he answered the question. Referring to the recorded discussion or notes was necessary to ensure the correct transcription of the respondents' views but limited our ability to treat the surveys quantitatively. We also relied on a strong assumption that the first factor mentioned was the most decisive, which we are not able to verify.

Although the work is still preliminary on how to combine quantitative and qualitative knowledge of fishers' behaviour, it draws interesting perspectives, notably for fishing behaviour modelling. It indeed suggests that a much larger set of factors should be included in fishery models to improve the implementation of fleet dynamics. It is also tempting to test statistically the significance of the factors mentioned by fishers to explain the choices evidenced in data or use them in behaviour models. With that said, the factors mostly cited (local weather, personal preferences) cannot easily be translated into a quantitative variable.

Lessons for SPF fishery management

SPF fisheries worldwide have been subject to crises that have forced fishers to adapt (Andrés and Prellezo 2012, Gamito et al. 2016, Quezada et al. 2023). These crises were due to the high variability of SPF availability, and worsened by their exposure to climate change (Gamito et al. 2016). Furthermore, SPF fisheries are often highly specialized, thus more vulnerable (Young et al. 2019).

Pelagic fisheries of the Bay of Biscay benefit from a larger portfolio of possible targets that have proved to be decisive for their resilience in the past. However, our study highlighted that the main sub-fleet targeting sardine in the BoB became strongly dependent on this species. This specialization is specifically significant for the Brittany purse seiners. Many vessels of this sub-fleet abandoned diversified strategies, known as more resilient (Anderson et al. 2017), to adopt a strategy that target sardine all year long. Our qualitative analysis showed that this specialization was not a strategic choice but forced by the loss of fishing opportunities on other SPF fishes. Depending on the species concerned, this loss was driven by economic, regulatory, or resource-related factors. The zero TAC on horse mackerel in 2023 illustrates this loss and further accentuates this forced specialization. Sardine, as a non-regulated species, thus became a primary target. The lack of priority given to economic factors at short time scales may also reflect this specialization. With little choice in the target species, fishers would always prioritize the sardine quantity landed (transcribed by the resource availability factor). The seasonal strategy reflected different levels of specialization between sardine-oriented trawlers and purse seiners. Trawlers have more diversified winter strategies, which allow them to adopt a seasonal strategy based on their expected revenues, i.e. switch to a summer sardine-oriented strategy when the price is suitable to them. On the contrary, purse seiners have a sardine-oriented strategy all year long, which does not involve a seasonal strategy.

However, the fishery for sardine in the Bay of Biscay faces new threats: the decreasing size of fishes (Véron et al. 2020) reduces the demand from the canning industry. The stock assessment results also show that the level of spawning stock biomass and the fishing pressure are respectively below and above the precautionary approach (ICES 2021), leading to the MSC label loss.

The management of SPF fishery in the BoB needs to adapt to this new challenge. The first possibility would be to adopt conservative and adaptative mono-specific management to prevent any resource collapse, following the example of the Peruvian anchovy fishery (Oliveros-Ramos et al. 2021). Daily management of purse seiners catches already exists in the BoB during winter to adapt the landings to the local market. This system is well accepted by fishers as it increases their efficiency and distributes profits between vessels. However, it does not solve their over-specialization on sardine and makes them vulnerable to any change in the behaviour of the canning industry.

The fishers surveyed valued their flexibility. They advocated for management measures that would strengthen it and ensure access to a variety of target species, in line with previous scientific work (Anderson et al. 2017). For SPF species, the quota share system was often criticized by the fishers surveyed for being disadvantageous for small-scale fisheries. Various options can be evaluated, such as pooling SPF quotas, managing quotas on a multi-year basis, or introducing socio-economic considerations in the sharing system (Le Floc'h et al. 2015). For other species, the main demand was to facilitate access to various fishing licenses to use other fishing gears, such as longlines for purse-seiners and bottom trawls for trawlers.

Another way for SPF fishers to diversify their activity is to develop new market opportunities. The anchovy market, in particular, would be interesting to rebuild for French SPF fishery. Anchovy is now abundant in the BoB but underexploited by French vessels compared to past catches before the 2005–2009 closure. Although multifactorial, this situation is driven by low and highly volatile prices (Uriarte et al. 2023). Promoting the cannery industry or introducing fishery labels promoting sustainability and/or locality (Zander et al. 2022) would be interesting solutions to investigate.

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Authors contributions

G.L. : investigation, formal analyzis, software, writing – original draft, writing – review & editing. F.D. and S.L. : conceptualization, methodology, supervizion, writing – review & editing conceived the research idea. .

Supplementary material

Supplementary data are available at *ICES Journal of Marine Science* Online.

Data availability

The data underlying the fleet analyses will be shared on reasonable request to the corresponding author. Limited data from the interviews (in aggregate form) can be shared upon request, when in compliance with GDPR regulations and the protection of the anonymity of the participants in the study.

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