Disentangling the dynamic of the Moored Fish-Aggregating Devices (MFADs) fleet in Guadeloupe using a stock-flow analysis

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Highlights

- Redeployment of fishing effort from coastal to MFADs fisheries remains unproven.
- A stock-flow analysis was applied to disentangle fleet dynamics and related fishing effort.
- MFADs fishers tend to reduce fishing effort in coastal fisheries.
- Mobility between fisheries is high and age is a driven factor.
- Regulations are required to improve attractiveness and fair access to MFADs fisheries.

Abstract

Fish-aggregating devices (FADs) have been used in centuries to attract fish and facilitate their captures. If drifting FADs developed at a large and industrial scale, moored fish-aggregating devices (MFADs) are mostly used by artisanal fishers and often implemented to shift the pressure away from depleted coastal fish stocks and toward large migratory pelagic fish populations. Indeed, as pelagic fish aggregate around these devices, MFADs allow small-scale fishers to access this resource and improve their income. If there are many studies on the development of MFADs, the underlying assumption that the development of the MFAD fishery leads to the redeployment of the coastal fleet toward large pelagic species remains unproven. In the French archipelago of Guadeloupe, Lesser Antilles (FAO area 31), an important small-scale MFADs fleet targeting dolphinfish and tuna species developed since the end of the 80s. We used a stock-flow framework to analyse fleet and sub-fleet dynamics and allocation of fishing effort between coastal and MFADs fisheries over the 2008-2019 period. We found that, in the context of a multi-purpose fleet, vessels operating on MFAD tend to decrease their coastal fishing effort and that MFAD fishery remained more attractive for younger fishers. Nevertheless, this fishery failed to attract enough newcomers to compensate the outflows of ageing fishers as working conditions and barrier to enter the fishery remains key issues. Improving attractiveness and fair access to the MFADs fishery requires better regulation and management.

Keywords: fish aggregating devices, small-scale, fleet, fisher behaviour, dolphinfish, MFADs quota.

1 Introduction

Floating structures such as logs, drifting algae, or dead animals, attract fish, both adults and juveniles (Dempster & Taquet, 2004). The reasons and mechanisms behind this behaviour are not well understood (Ehrardt et al., 2017) but fishers have taken advantage of it for centuries with Fish Aggregating Devices (FADs). FADs are artificial structures meant to trigger this natural fish behaviour and concentrate pelagic fish at a known place to facilitate their capture (Dempster & Taquet, 2004). First used in the form of moored Fish-aggregating Devices (MFADs), anchored to the seafloor, they were developed later as drifting Fish-Aggregating Devices (DFADs), that could be in the middle of the ocean. These drifting FADs started to develop at an industrial and large-scale fishery during the second half of the 20th century and especially since the 1990s, changing the levels and patterns of stock exploitation (Dempster & Taquet, 2004) while technological improvement made it more and more efficient (Ehrardt et al., 2017). Following this rapid development, especially by tuna fisheries, concerns grew about the environmental impacts of the device. Although FADs may not increase the risk of overfishing and by-catch in tuna fisheries compared to other fishing practices (Dagorn et al., 2012), its rapid development and the total amount of by-catch (100,000 t per year according to Scott & Lopez, 2014) led to various investigation to improve its management and monitoring practices (Scott & Lopez, 2014; Davies et al., 2014).

For their part, MFADs are mostly used in small-scale fisheries and contrarily to drifting FADs, they are usually low-tech, typically made of one or a set of buoys, often some additional devices to increase fish aggregation (like trawling nets, plastic sheeting or lashing straps) and anchored to the seafloor with a mooring rope and a steel or concrete block. As large pelagic fish gather around the devices, they reduce the search time, the fuel and effort from fishers and make resources with a high commercial value accessible to small-scale fishers (Guyader et al., 2017). The issue of food security related to MFADs was also considered in several regions (Albert et al. 2014; Campbell et al. 2016).

When the first MFADs were installed in Guadeloupe at the end of the 80s, there were three main objectives for their development: decrease the pressure on depleted inshore fish stocks, increase fisher revenues and reduce the island dependency on fish imports (Guyader et al. 2013). Nevertheless, the assumption that the development of MFAD would lead to the redeployment of fishing efforts away from the coastal fish stocks remains unproven. Moreover, in the context of a small-scale fishery such as Guadeloupe, with multipurpose vessels combining different coastal and offshore pelagic metiers, studying MFAD can also be complex. The availability of data is another constraint as device-owners often fail to declare their location and characteristics which complicates the study of MFADs, as well as their management (Alvard et al. 2015; Guyader et al., 2017; Widyatmoko, 2021). In these conditions, understanding the use of MFADs, its evolution and its relationship with the development of the redeployment of the fishing effort away from coastal fisheries is critical to assess and potentially improve MFAD management programs in Guadeloupe and elsewhere.

To do so, we used datasets on fleet characteristics, fishing activity and related effort from 2008 to 2019. Even though consistent data on the location and ownership of MFADs was missing, the activity data per metier allowed us to categorise the Guadeloupean vessels into different fleets and sub-fleets and to analyse their activity on these different metiers, including their use of MFAD. To go beyond an analysis of the population of vessels in these fleets and sub-fleets, we also analysed the flows of vessels moving from one fleet to the other every year using a stock-flow framework for vessels adapted and enhanced from Quillerou and Guyader (2012). The stock-flow framework was also conducted for the population of vessel-owners in order to better understand the changes in fleet structure. A statistical analysis was carried out to test whether the flows were significant. Finally, we studied the evolution of fishing effort (days at sea) per metier in the relation to these changes.

This paper also aims at filling a knowledge gap on the use of MFAD in small-scale fisheries. Research on FADs has been developed in the past decades mainly to understand the ecology of FAD fisheries (Dempster & Taquet, 2004; Taquet, 2013). In addition, most studies considered the short-term implications of the introduction of MFADs through the analysis of catch per unit of effort and catch composition (see for example Eighani et al. 2019) or comparison of profit margins between MFADs and coastal fisheries (Guyader et al. 2013;), but rare are the studies that seek to assess the medium and long-term impacts of MFADs on the fleet structure and the allocation of fishing effort between fisheries. Montes et al. (2019) studied perceived and self-reported livelihood assets — natural, financial, physical, social, and human — of MFADs and non MFADs fishers in a selection of Caribbean islands in order to better understand the factors explain the entry in MFADs fisheries.

2 Description of the case study

The archipelago of Guadeloupe is a French overseas region located in the Caribbean, in the Lesser Antilles area (FAO area 31). Prior to the end of the 80s and the first establishment of experimental MFADs, trolling was the traditional way of fishing dolphinfish. Fishers travelled long distances looking for logs or flocks of birds that would indicate schools of dolphinfish (Taquet et al. 2000). Following a successful experimental period, private MFADs rapidly expanded with a growing number of vessels involved. Their number rise from 50, 150, 300 vessels in 1990, 1995, 2000 respectively (Mathieu et al. 2013). This development phase was followed by a stabilisation phase until 2007 before the number of vessels began to decline to reach around 200 vessels in 2019 (Guyader, 2019). In 2019, total landings of large pelagic species were 1600 tons for a total value of 13 million euros. The main target species were dolphinfish (*Coryphaena hippurus*) (61%), yellowfin tuna (*Thunnus albacares*) (18%), blue marlin (*Makaira nigricans*) (8%), triggerfish (*Canthidermis maculatus*) (7%) and other miscellaneous species like wahoo (*Acanthocybium solandri*), rainbow runner (*Elagatis bipinnulata*) and other tunas (Guyader et al., 2013). Trolling lines, surface and drifting vertical baited lines were the main gears used by fishers (Reynal et al. 2015). Most of vessels were less than 10 meters long, open decked with outboard engines and they fished typically during one-day fishing trips. MFADS are generally set from 5 to 45 naut. miles offshore, at depths between 500 and 5,000 meters (Guyader et al. 2018). MFADs regulation goes back to 1994 and was incorporated in the Prefectural Order of 2002 regulating marine fisheries in Guadeloupe[1]. However, this regulation was poorly enforced and the exact number of MFADs was not known by the maritime authorities (Guyader et al., 2017).

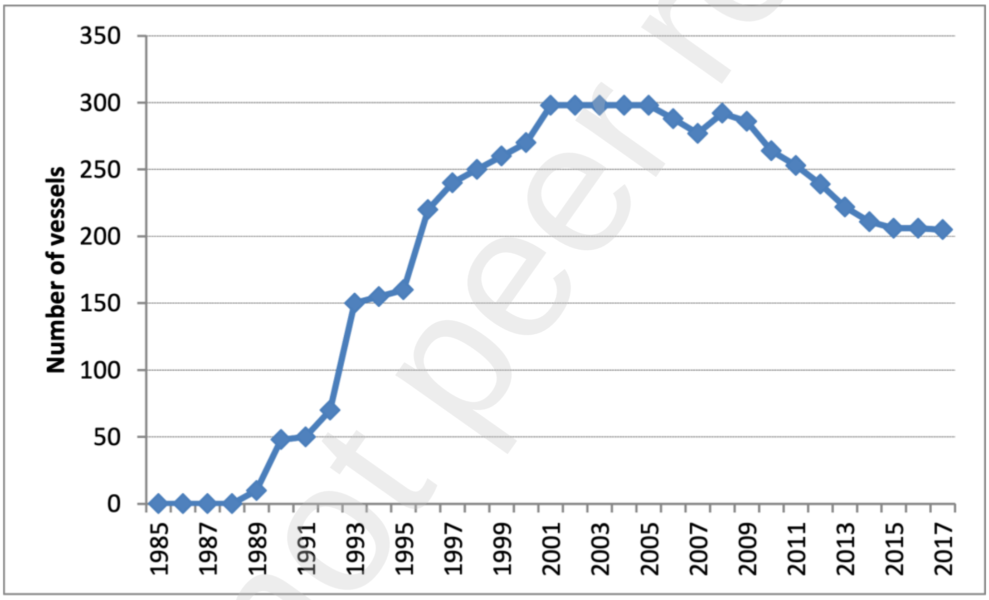

Figure 1: Number of vessels operating on MFADs (Guyader, 2019)

These small-scale vessels may also operate in coastal fisheries, using pots, gillnets and hand lines to target demersal species such as snappers, parrotfish or groupers. Other fisheries related to the insular shelf are spiny lobsters, conchs and small pelagic fisheries[2]. There is also a small deep-sea fishery around 200 meters depths where snappers are targeted with small longlines and gillnets. In 2019, the Guadeloupean fleet was composed of 691 vessels, among which 484 were active. Their average size and horsepower were 7.7 meters and 172 kW respectively. Most of the vessel-owners were from Guadeloupe and skipper of their vessel. Crews usually consist of two people.

As a French Outermost Region, Guadeloupe is part of the European Union and subject to the Common Fishery Policy (CFP). The main CFP rules concern fleet total capacity expressed in vessel horsepower (kW) and a non-constraining national quota derived from a TAC set by ICCAT for blue

[1] Arrêté n°2002/1249/PREF/SGAR/MAP du 19 août 2002 portant réglementation de l'exercice de la pêche maritime côtière dans les eaux du département de la Guadeloupe. According to these regulations, MFADs can be installed by commercial fishers after authorization has been granted by the local maritime authorities.
[2] The Guadeloupean continental shelf is narrow and mainly composed reef ecosystems.

marlin (Guyader, et al., 2019). Subsidies for building new vessels were banned in 2004 at EU level and the last vessels built with public aids entered the Guadeloupe fleet in 2008. No decommissioning schemes have ever been established in Guadeloupe and the only constraint to access the fisheries is the possession of an exploitation permit (Guyader, et al., 2019). Fisheries in Guadeloupe are regulated through mainly technical measures (mesh size and species landings size) and most of the fisheries are open access with no *numerus clausus*. This is the case for the coastal fisheries and for the pelagic MFADs fishery.

3 Material and method

Data used in this study come from the Fishery Information System (FIS) of the IFREMER (Weiss et al., 2020) and were collected between 2008 and 2019 under the Data Collection Framework regulation of the Common Fishery Policy[3]. This study is based on two complementary datasets. The first dataset called FLEET includes annual data of all the commercial vessels registered in Guadeloupe, both active and inactive, and their characteristics such as the size, power and age. It also includes information about the vessel-owners such as their identification number, name and age. The second dataset, called EFFORT, provides fishing effort, defined as the number of fishing days per metier and per vessel. The number of fishing days is given per month and then aggregated per year. We used the data on fishing effort per metiers to group vessels with a similar fishing strategy into different fleet and sub-fleets organised in three levels as described on Figure 2.

[3] REGULATION (EU) 2017/1004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2017 on the establishment of a Union framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the common fisheries policy and repealing Council Regulation (EC) No 199/2008 (recast). JOUE L 157/1 20.6.2017.

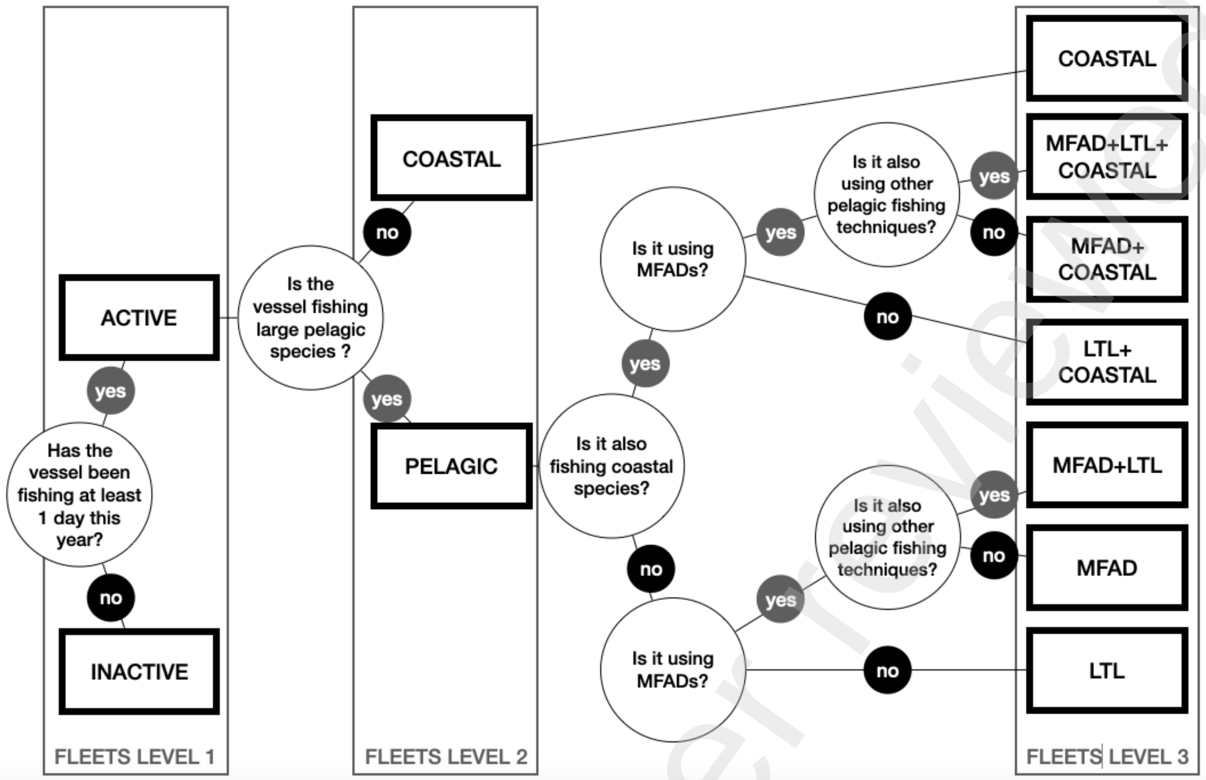

Figure 2: Categorisation in fleets and sub-fleets according to fishing effort, gear used, and fish targeted.

At the first level, the vessels were allocated in two main fleets: the 'active' and the 'inactive' fleets, depending on whether they had been fishing or not during the year considered (Figure 2). At the second level, the active fleet was divided between vessels that harvest large pelagic species (pelagic fleet) or not (coastal fleet). The third level had a specific focus on the pelagic fleet and the vessels were categorised on different sub-fleets depending on different combination of metiers. We separated the pelagic vessels that were fishing also coastal species from the vessels that were fishing only large pelagic species, and within these sub-fleets, the vessels that were operating around MFADs using different lines techniques from the vessels that were using trolling lines (LTL) on free schools or combining both. We ended up with seven sub-fleets, including six pelagic sub-fleets.

We complemented this vessels categorisation with a categorisation of vessel-owners at the levels one and two. We considered vessel-owners as pelagic if they owned at least one pelagic vessel. For each fleet or sub-fleet level, the stock (number) of vessels and vessel-owners were considered each year and we analysed the flows of vessels and vessel-owners year-on-year thanks to a stock-flow framework.

3.1 Stock-flow framework

Based on the former segmentation, the stock-flow framework from Quillerou and Guyader (2012) was used and adapted here to better understand the dynamics of fleet and vessel-owners over time. This framework includes the stocks of vessels and vessels-owner at different fleet level (1, 2 and 3) represented by squares in Figure 3 and the related inflows of entries and outflows of exits represented by arrows. Each year, the stock of vessels in the fleet or sub-fleet receives different inflows: newly built vessels (arrow v1) and entries of inactive vessels resuming their fishing activity (arrow v2). Outflows are determined by exits of vessels becoming inactive (arrow v3) knowing that a fraction of these vessels leaves the fleet definitely (arrow v4). Within the active fleet, other types of inflows and outflows may occur each year as some vessels move from the coastal fleet stock of vessels to the PELAGIC fleet stock of vessels and vice versa (arrows v5 and v6). Flows between sub-fleets within the PELAGIC fleet were also considered but were not represented on Figure 2. The stock of active vessel-owners is also supplied by owner inflows (new entries represented by arrow o1) and outflows considers exit of vessel-owners (arrow o2). Transactions of vessels between vessel-owners are also represented by white arrows on the second-hand market shape on Figure 3. These changes may lead to change in the vessel strategy and by consequence a change of fleet (arrow t2) or not (arrows t1).

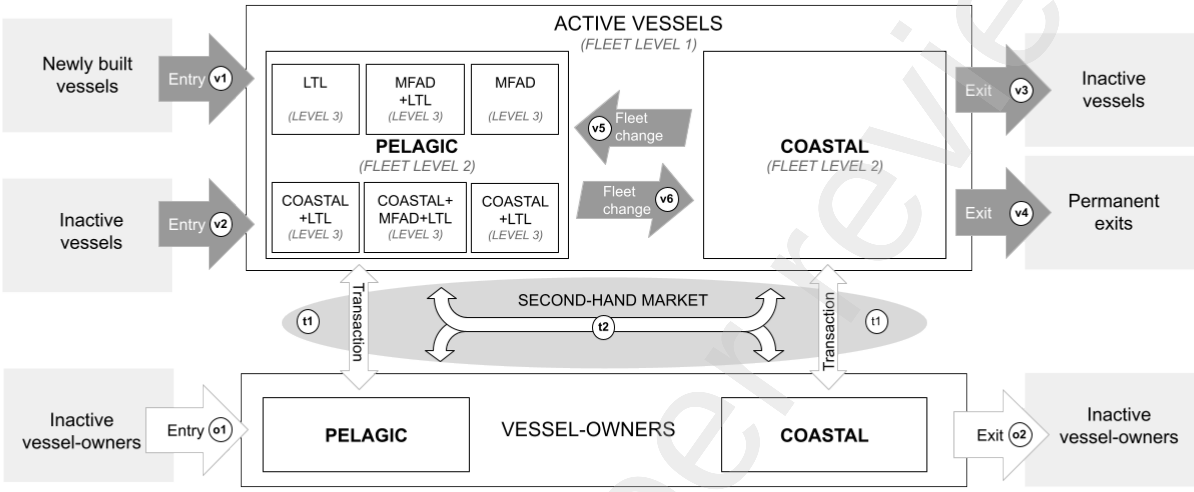

Figure 3: Stocks-flows approach applied to the Guadeloupe fleet.

3.2 Stock-flow analysis

The analysis was performed in three main steps over the 2008-2019 period. As the data was available from 2008 to 2019 and we needed a year *t-1* in our analysis, our year *t* range from 2009 to 2019. First, we performed a descriptive analysis at the fleet level one, to understand the flows of exits and entries in and out of the active fleet, both for vessels and vessel-owners. It included a focus on different characteristics of the fleets such as the size, power and age of the vessels and the age of the vessel-owners. During the second step, we analysed the flows and stocks evolution at the levels 2 and 3, for the coastal and pelagic fleet as well as for the different pelagic sub-fleets. During this step, the descriptive analysis was complemented by a statistical analysis to test if the differences between the flows were significant.

Considering F the different fleets excluding the inactive fleet (inactive) with $X_{v,t}$ the fleet of the vessels v for time t.

$\{v|X_{v,t} = f\}$ is the set of vessels of a given fleet $f \in F$ for time t.

$p_{i,j}^{t} = P(X_t = j/X_{t-1} = i)$ is the probability for a given vessels to move from a fleet i to a fleet j between t-1 and t.

The cardinal number of the set of vessels of a fleet i at time t is Card($\{X_t = i\}$) = n($\{X_t = i\}$). The number of vessels moving from the fleet i to a fleet j between *t-1* and t is given by $n_{i,j}^{t} = n$ $(X_t = j/X_{t-1} = i)$.

The number of vessels n in the active fleet at time t is defined as follows:

$$n(X_t \in F) = n(X_{t-1} \in F) + n(X_t \in F/X_{t-1} \notin \{F, Inactive\}) + n(X_t \in F \;/\; X_{t-1} = Inactive\}) - n \,(X_t = Inactive \;/\; X_{t-1} \in F) - n(X_t \notin \{F, Inactive\} \;/\; X_{t-1} \in F)$$

Considering the number of vessels *n* in the active fleet at time *t-1*, the respective entry flows v1 and v2 and exit flows v3 and v4 between time *t* and *t-1* (see Figure 3).

In a second step, we applied the same formula to fleet level 2 by considering the pelagic, coastal fleets including the exchange flows of vessels between these fleets (arrows v5 and v6 on Figure 3). We went further by looking at the possible trajectories offered to a vessel in any fleet for the next year, as a result of these flows. Three possible trajectories are given to a vessel in any fleet for the next year: staying in their fleet, changing fleet, becoming inactive. Let W={*Pel*,*Coast*,*Inactive*} be the fleet typology (level 2) with *Pel* and *Coast* characterizing the pelagic and coastal fleets. For each fleet - with the case of the pelagic fleet detailed below - we looked at the proportion of vessels following each of these trajectories $p_{Pel,Pel}$, $p_{Pel,Coast}$ and $p_{Pel,Inactive}$ with:

$$p_{Pel,Pel}^{t+1} = \frac{n(X_{t+1} = Pel/X_t = Pel)}{n(X_t = Pel)} = \frac{n_{Pel,Pel}^{t+1}}{\sum_{w \in W} n_{Pel,w}^{t}}$$

$$p_{Pel,Coast}^{t+1} = \frac{n(X_{t+1} = Coast/X_t = Pel)}{n(X_t = Pel)} = \frac{n_{Pel,Coast}^{t+1}}{\sum_{w \in W} n_{Pel,w}^{t}}$$

$$p_{Pel,Inactive}^{t+1} = \frac{n(X_{t+1} = Inactive/X_t = Pel)}{n(X_t = Pel)} = \frac{n_{Inactive,Coast}^{t+1}}{\sum_{w \in W} n_{Pel,w}^{t}}$$

With $p_{Pel,Pel}^{t+1} + p_{Pel,Coast}^{t+1} + p_{Pel,Inactive}^{t+1} = 1$

The same calculation was also conducted each year for the coastal fleet and the different pelagic sub-fleets (level 3). We then compared the proportions between each fleet using a statistical test to see if there was a statistical difference. For instance, we compared each year the proportion of pelagic vessels becoming coastal $p_{Pel,Coast}$ to the proportion of coastal vessels becoming pelagic $p_{Coast,Pel}$. As we compared two proportions and as the population was large enough (more than 30 vessels in each fleet each year), we used a two-probability z-test (NCSS, 2021). Applied to our example, this statistical test follows the formula:

$$Z_t = \frac{p_{Coast,Pel}^{t} - p_{Pel,Coast}^{t}}{\sqrt{p_{Pool}^{t}(1 - p_{Pool}^{t})(\frac{1}{n_{Coast,Pel}^{t}} + \frac{1}{n_{Pel,Coast}^{t}})}}$$

With p_{pool} the total pooled proportion calculated as:

$$p_{Pool}^{t} = \frac{p_{Coast,Pel}^{t}.n_{Coast,Pel}^{t} + p_{Pel,Coast}^{t}.n_{Pel,Coast}^{t}}{n_{Coast,Pel}^{t} + n_{Pel,Coast}^{t}}$$

For each test, the significance level considered was for a p-value < 0.05. We compared the proportions from the pelagic and the coastal fleet (level 2), then from the six pelagic sub-fleets.

3.3 Analysis of the evolution of the fishing effort

Finally, to disentangle the Guadeloupean fishers' behaviour, an analysis of the fishing effort (days at sea) by metier for each fleet and sub-fleet was finally carried out. First, we described the evolution of the number of coastal fishing trips, the pelagic fishing trips and the MFAD fishing trips between 2008 and 2019. Then, we studied the evolution of these different types of fishing trips per fleet. Indeed, if the coastal fleet only operates on coastal metiers, pelagic vessels can use a combination of coastal metiers, and pelagic metiers. Therefore, we made a differentiation between the coastal fishing trips by coastal vessels and the coastal fishing trips by pelagic vessels and looked how they evolved. We also analysed the evolution of the MFAD related fishing trips, and the LTL fishing trips to characterise the behaviour of pelagic vessels.

4 Results

4.1 Analysis at fleet level 1 for vessels and vessel-owners

Figure 4 shows the evolution over the period 2008-2019 of the number of vessels in the active fleet (in black) as well as the inflows (upward bar composed of newly built vessels and vessels resuming their activity) and outflows (downward bar composed of vessels becoming inactive). Table 1 is complementary and includes the number and characteristics of active vessels in 2008 and 2019, news entries between 2009 and 2019 (both newly built vessels and vessels resuming their activity as well as vessels that left permanently the fleet (which is different from vessels that became inactive and resumed their activity afterwards). As Figure 4 shows the flows year-on-year, this distinction was not made and the outflows of vessels becoming inactive includes the vessels that are leaving the fleet permanently and those that would resume their activity later on.

Between 2008 and 2019, the active fleet decreased by 277 vessels (-36.4%), from 761 vessels in 2008 to 484 vessels in 2019 (Table 1) and the cumulated power of the whole active fleet (black line on Figure 4) also decreased by 19%, from 101,000 kW to 82,000 kW. As a result, the average vessel power increased (+34 kW) as well as the average vessel length (+0.42 m) (Table 1). During this period, there were 309 unique vessel entries, 178 of them (+57.6%) were newly built vessels while 131 other entries (+42.4%) were inactive vessels that resumed their activity (Table 1).

The number of newly built vessels each year decreased significantly during the period, from 38 in 2008, to 7 in 2014 and on average 10.8 vessels per year between 2015 and 2019 (with a standard deviation of 1.7). This shows a marked decline in constructions over the period. As illustrated on Table 1, the newly built vessels were larger (+1.04 m) and more powerful (+83 kW) on average than the fleet in 2008. The vessel-owners for these vessels also tend to be younger (-3.6 years) than the average of vessel-owners in the existing fleet in 2008.

The vessels that resumed their activity did not show such a clear tendency: they increased from 45 in 2009 to 80 in 2011, then decreased in 2016, before increasing again to 65 entries in 2017. It does not follow the same pattern as the decrease in vessel constructions.

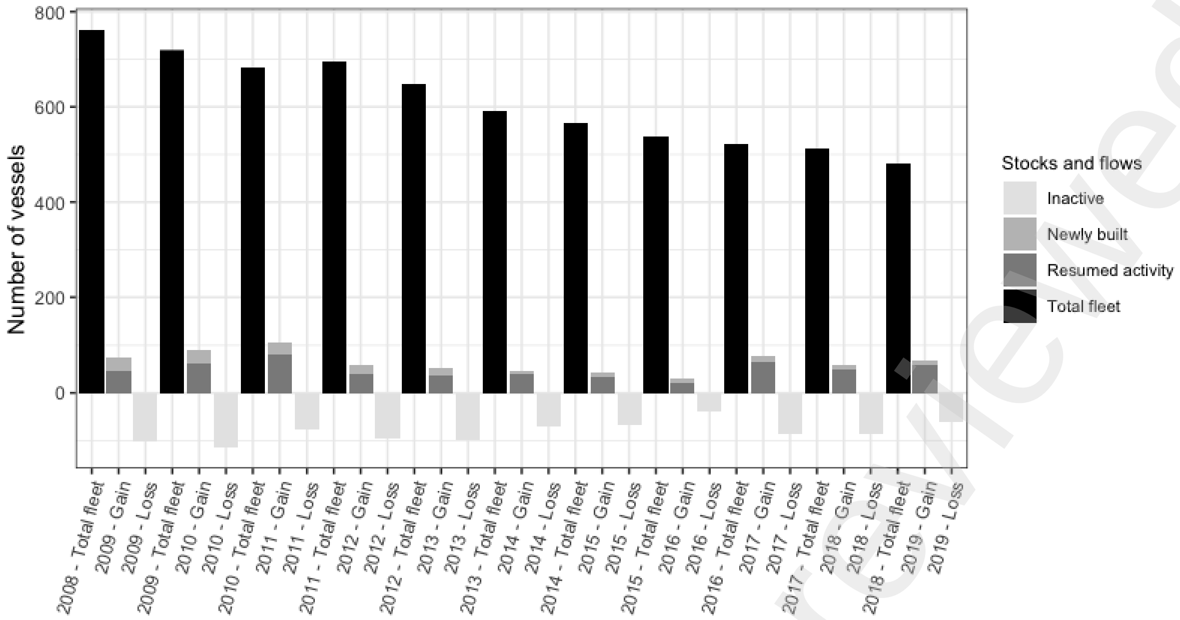

Figure 4: Inflows, outflows, and evolution of the number of vessels.

In total, 586 vessels left definitively the active fleet between 2009 and 2019 and 159 left at least once but resumed their activity later. Vessels that permanently exited the fleet were 15.3 years-old on average and vessel-owners leaving the fleet were 50.2 years-old on average. Even though older vessels were leaving, and younger ones entering the fleet, the active fleet had been ageing between 2008 and 2019, both in terms of the vessel and vessel-owner average age (+6.2 years for both) (Table 1).

Table 1: Characteristics of the vessels depending on whether they entered, exited, or remained in the active fleet between 2008 and 2019.

	Number of vessels	Average length (meter)	Average power (kW)	Vessel average age	Vessel-owner average age
Active fleet in 2008	**761**	**7.32**	**136**	**10.0**	**45.6**
Active fleet in 2019	**484**	**7.74**	**170**	**16.2**	**51.8**
Permanent exits	**586**	**7.35**	**149**	**15.3**	**50.2**
New entries since 2009	**309**	**8.04**	**184**	**6.7**	**43.9**
Newly built vessels	178	8.36	209	0	42.0
Resumed activity	131	7.67	156	14.4	46.0

In 2008, there were 710 active vessel-owners in the fleet. Between 2008 and 2019, 331 vessel-owners entered the fleet and 577 left, showing an important mobility of fishers. There were 464 active fishers left in the fleet in 2019.

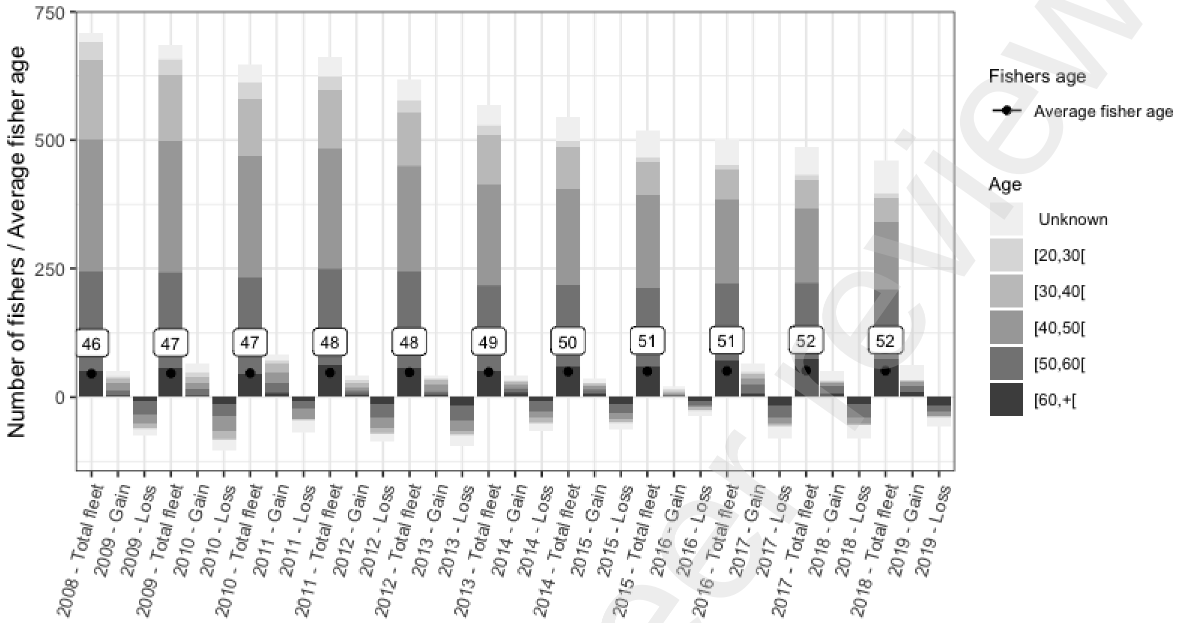

Figure 5: Inflows, outflows, and evolution of the number of vessel-owners according to their age.

As shown on Figure 5, the number of fishers aged 50 or older only decreased by 9%, from 243 in 2008 to 221 in 2019, while the number of fishers younger than 50 decreased by 63%, from 447 to 164. As a result, fishers older than 50 represented 47% of the fleet in 2019, while they represented only 34% of the fleet in 2008. The population of vessel-owners is ageing with an average age increasing from 46 years-old in 2008 to 52 years-old in 2019 (Figure 6). The fishers older than 60 even increased from 52 fishers in 2008 to 80 in 2019 representing 17% of the vessel-owner population. Even if the legal age for retirement is 55 years old, a larger proportion of vessel-owners do not retire and continue to operate vessels.

It is interesting to note that there tend to be a higher proportion of younger vessel-owners in the pelagic fleet than in the coastal fleet. In 2008, 6.4% of the pelagic fleet was between 20 and 30 years-old and 27.9% was between 30 and 40 while only 1.7% and 14.4% of the coastal fishers were in these respective age categories. Over the period, the proportion of younger fishers decreased in both fleets. In 2019, 4.1% of fishers were between 20 and 30 years old in the pelagic fleet, for less than 1% of vessel-owner in this age category in the coastal, and 16.6% of fishers between 30 and 40 for 6.9% in the coastal fleet. In 2019, vessel-owners younger than 50 still represented 60% of the pelagic fleet in 2019, and only 33% in the coastal fleet.

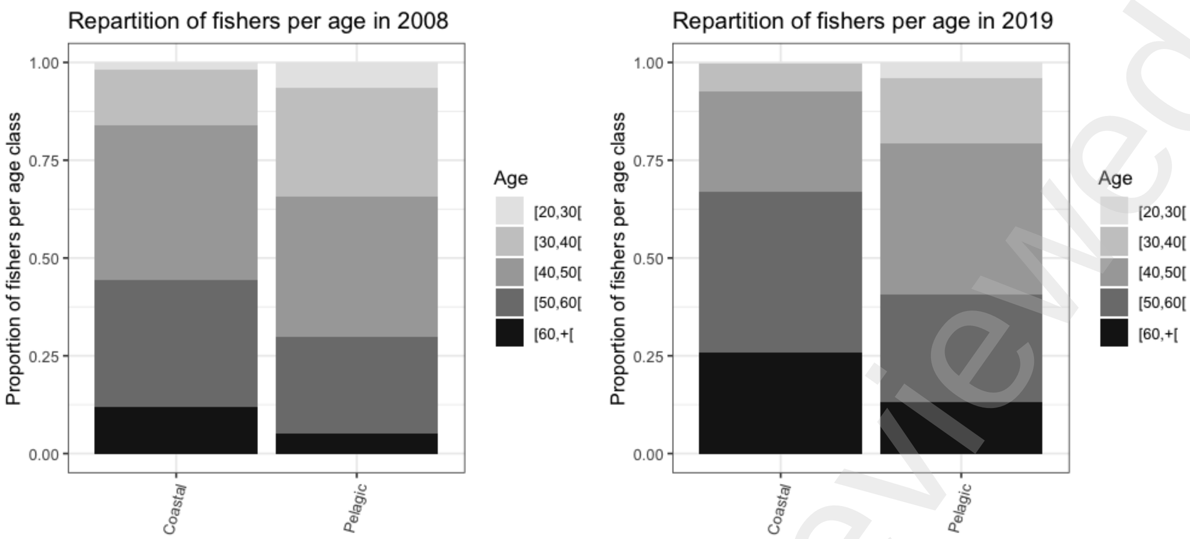

Figure 6: Repartition of vessel-owners per age and per fleet in 2008 (left) and in 2019 (right).

The transactions of vessels (i.e., the vessels sold on the second-hand market) was limited in scope over the period. The annual transaction rate was only 2.2% on average showing that these flows have a limited impact on the evolution of the structure of the fleet. It is interesting to note that the fall in the number of new constructions was not compensated by an increase in the purchase of second-hand vessels.

4.2 Analysis of the coastal and pelagic fleets (level 2) and of the pelagic sub-fleets (level 3).

While, overall, the active fleet decreased by 36.4% (277 vessels) from 2008 to 2019, the pelagic fleet decreased by 241 vessels (-55.4%), from 435 vessels in 2008 down to 194 vessels in 2019. The coastal fleet only decreased by 11%, from 326 vessels in 2008 to 290 vessels in 2019. Though the pelagic fleet decreased overall during the period, 335 vessels entered the fleet at some point. Among these new entries 119 (35.5%) were newly built vessels, 72 (21.5%) were vessels that resumed their activity and 144 (42.9%) came from the coastal fleet.

Newly built vessels were a particularly important flow of vessels for the pelagic fleet as 76% of these vessels enter the pelagic fleet rather than the coastal one during their first year of activity, which shows a certain attractiveness of this fleet. Nevertheless, it failed to keep the vessels in the long term and most of the new entries (66.9% or 224 vessels) had left the pelagic fleet by 2019. In addition to these exits, 81% of the vessels (352 vessels) that were originally in the pelagic fleet in 2008 had left by 2019. 71% of them had become inactive, and 29% (102 vessels) had left for the coastal fleet.

The coastal fleet counted 196 new vessels in 2019 compared to 2008, 28% of them were newly built vessels, 52% were in the pelagic fleet in 2008 and the rest (20%) were vessels that resumed their fishing activity. In terms of outflows from the coastal fleet, 69% (225 vessels) of the vessels that were originally in the coastal fleet in 2008 had left by 2019. The majority (94%) had become inactive and only 6% of them had become pelagic. We could see that the flows between the active and inactive fleets, and between the coastal and pelagic fleets were very important as only as only 73 vessels (9.6%) remained active and in the same fleet (coastal or pelagic) the whole period.

At level 2, looking at the inflows and outflows from the pelagic fleet year on year, we found that, on average, 74.4% of the pelagic vessels on year t remained in the fleet on year t+1 (with a standard deviation (SD) of 7.1), 12.2% became inactive (SD = 3.0) and 13.4% entered the coastal fleet (SD = 5.4). Regarding the coastal fleet during the same period, on average, 76% of the coastal vessels remained in the coastal fleet every year (SD = 6.1), 14% became inactive (SD = 4.5) and 8.9% of the coastal vessels entered the pelagic fleet (SD = 3.4). Several z-test comparing the proportion every year showed that there were significantly more pelagic vessels becoming coastal than coastal vessels becoming pelagic for only 4 years out of 11 —in 2018 ($p = 0.009$), 2017 ($p < 0.001$), 2013 ($p = 0.008$) and 2009 ($p = 0.041$).

At level 3, looking at the sub-fleets, we found that vessels that were in the pelagic fleet but also having a coastal activity (coastal+pelagic) had more chance to become pure coastal (and quit their pelagic activity) than pure pelagic. On average over the period, these coastal+pelagic vessels had 15.6% chance to become coastal the following year (SD = 6.2) and only 3.7% chance to become purely pelagic (SD = 2.5). The two-proportion z-tests confirmed that the difference is significant in all years except 2015. We also found that pure pelagic vessels had more chance to start a coastal activity than pure coastal vessels to start a pelagic activity. Indeed, on average during the period, only 8.5% of coastal vessels became coastal+pelagic the next year (SD = 3.2) while 20.9% of the pure pelagic vessels became coastal+pelagic (SD = 10.1). The difference was significant 7 years out of 11.

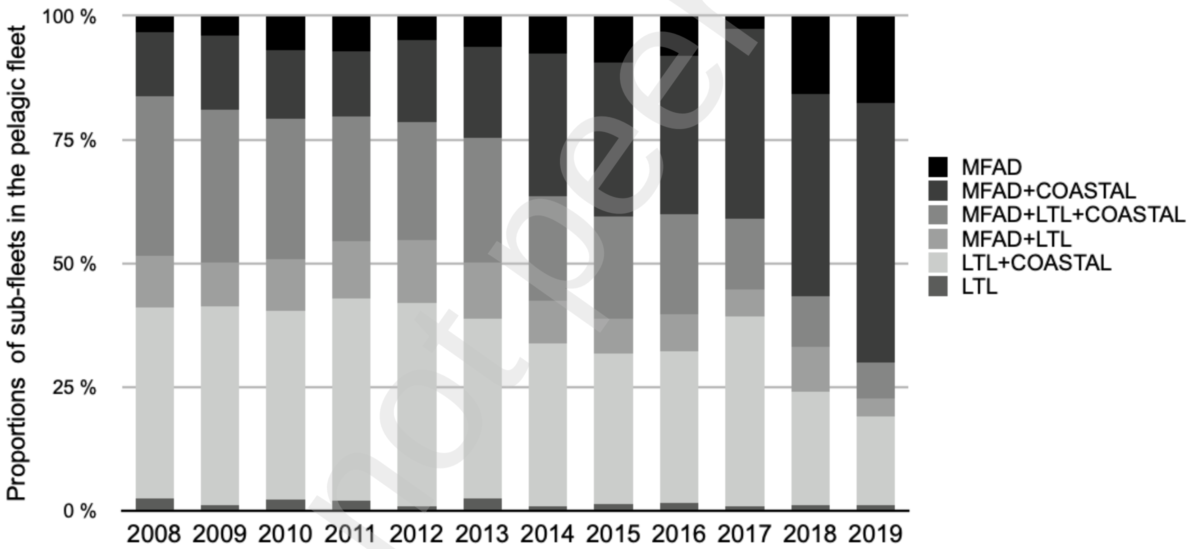

Figure 7: Repartition of sub-fleets within the pelagic fleet

When comparing the vessels using MFAD or LTL metiers (see Figure 2), we also found that vessels using only LTL metier had more chance to become coastal every year than vessels using MFADs. Indeed, between 2008 and 2019, on average 28.2% (SD = 18.1) of the LTL vessels became coastal for only 9.5% of the MFAD vessels (SD = 4.7). Two-proportion z-tests confirmed that the difference between the trajectory of MFAD and LTL vessels was significant 8 years out of 11.

Overall, the part of purely pelagic vessels in the pelagic fleet increased from 16% in 2008 to 22% of the pelagic fleet in 2019. This is mostly due to the decline of the LTL+coastal vessels (that were not using MFAD) as they decreased from 140 vessels in 2008 (32.2% of the pelagic fleet) to only 14 in 2019 (7.2% of the pelagic fleet) (Figure 7 and Figure 8). It shows that MFAD were becoming unavoidable in the pelagic fleet during the period. Indeed, the number of vessels using MFAD decreased by 26%, from 284 vessels in 2008 to 178 vessels in 2019 (Figure 8), but, as the other pelagic vessels (not using MFAD) decreased by 89%, from 151 to 16 vessels (Figure 8), the proportion of vessels using MFAD increased from 67% of the pelagic fleet in 2008 to 92% in 2019 (Figure 7). On the contrary, the proportion of vessels using LTL at least occasionally decreased from 84% to 30% (Figure 7). The proportion of vessels fishing exclusively on MFAD increased from 3% in 2008 to 18% in 2019 and the proportion of vessels using MFAD and fishing on coastal metiers jumped from 13% to 53% of the fleet, representing the most common fishing strategy in the pelagic fleet in 2019 (Figure 7). This also shows a decrease in the opportunistic pelagic fishing as vessels tend to fish more on MFADs that need to be bought and installed beforehand.

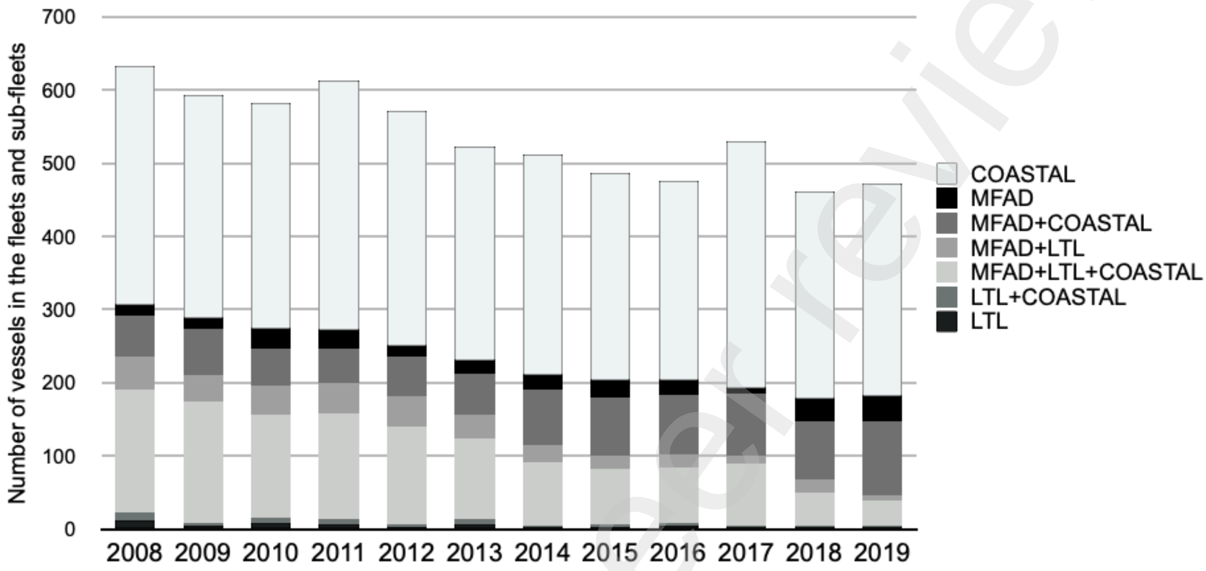

Figure 8: Number of vessels per sub-fleet between 2008 and 2019

4.3 Implications in terms of effort allocation between coastal and pelagic fisheries and between MFAD and other pelagic metiers

In terms of number of days at sea, the fishing activity decreased by 37% between 2008 and 2019, from 68,900 to 43,400 sea trips, which follows the decrease in the total active fleet (-36%). Looking at the coastal activity, we found that, the number of coastal fishing trips decreased by 38% while the coastal fleet only decreased by 11%. That is explained by the fact that most of the decrease in coastal activity comes from the pelagic fleet: the coastal fishing trips from the pelagic fleet decreased by 70% while the coastal fishing trips from the coastal fleet only decreased by 4% (Figure 9).

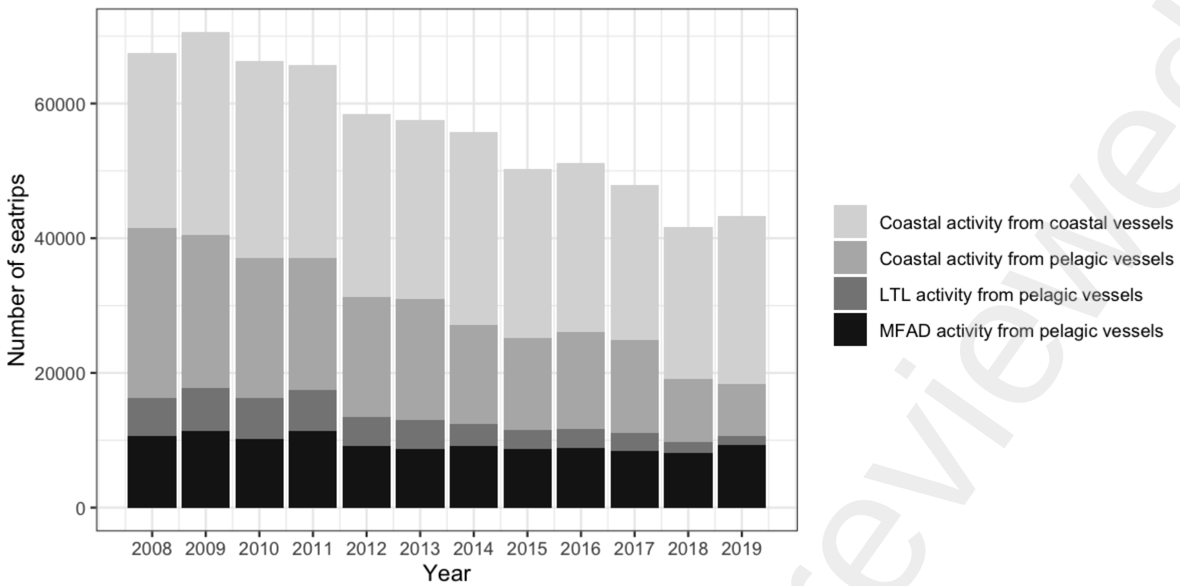

Figure 9:Number of fishing trips per fleet and type of activity

Similarly, the number of fishing trips by pelagic vessels targeting coastal species decreased by 70% between 2008 and 2019, while the fishing trips targeting pelagic species were only reduced by 34%. As a result, the pelagic activity represented 58% of the total fishing effort of the pelagic fleet in 2019, while it was only a minor part (39%) of its fishing effort in 2008. This shows an increased separation between pelagic and coastal fishing and important change in the fishing behaviour of Guadeloupean fishers that are less prone to shifting easily between different fishing activities.

More specifically, the proportion of MFAD fishing effort in the pelagic fleet fishing effort also grew. While the number of vessels fishing on MFAD (including vessels fishing also on LTL and coastal metiers) decreased by 37%, from 284 to 178 vessels (Figure 8), the number of sea trips on MFAD only decreased by 12%. The rest of the fishing activity by the pelagic fleet decreased at a greater rate: -77% for LTL fishing trips and -70% for coastal fishing trips by pelagic vessels. As a result, the proportion of MFAD activity in the pelagic fleet activity increased from 26% in 2008, to 51% in 2019. This shows the growing importance of MFAD within the pelagic fleet.

5 Discussion

Looking at the evolution of the total fishing effort deployed by the Guadeloupe small scale fishing fleet showed that the share of fishing effort dedicated to harvesting large pelagic species with MFADs increased over the period compared to the effort on coastal fisheries. Moreover, we also found that pelagic vessels operating on MFADs tended to reduce their coastal activity to increase their focus on the pelagic effort. From this, one could conclude that MFADs have had a positive effect in reducing fishing pressure on coastal reef fisheries. However, this result must be put into perspective. First, total fishing effort fell sharply over the period - both in its pelagic and coastal components - and this is explained by a reduction in the number of active vessels in the fleet. We found that more vessels and vessel-owners were leaving the active fleet each year than new vessels and vessel-owners entering it. Smaller and less powerful vessels tend to leave first, replaced by more powerful and slightly larger ones, owned by younger fishers operating for most of them

MFAD vessels. Nevertheless, this inflow of younger fisher was not sufficient to renew the fleet (including the pelagic fleet), which decreased and got older during the period.

Looking at the trajectories of fishers according to their age confirmed the previous work in the area (Guyader et al. 2013): the pelagic fleet is still more attractive to younger fishers, while the coastal fleet attracts older fishers. Our results showed that the older the fisher, the higher the probability to leave the pelagic fleet. This result is shared by other Caribbean MFADs fisheries where recent adopters of MFADs were also younger than long term MFADs users and even younger than non-MFADs users (Montes et al. 2019). Indeed, even though pelagic fishing was on average a more profitable activity than most coastal metiers, fishers had to go further offshore to get their catch and spent a longer time at sea (two or three times longer than in coastal fisheries) to make the best use of the gas spent (Guyader et al. 2013). Fishers also faced safety at sea and working conditions issues, making it potentially less desirable for an older population (Diaz et al. 2006). Moreover, the cost of new more powerful fishing vessels increased over time and the ban of subsidies for newly built vessels in 2004 by the EU also reduced the economic incentives to enter the fishery (Guyader et al. 2022). Another result is that, even though the coastal activity by the pelagic fleet decreased, a significant part of the pelagic fleet still showed some coastal fishing activities. One explanation can be found in the different risks related to the different fishing options. As previously described by Mathieu et al. (2013), pelagic fishers often complemented their pelagic activity with coastal activity (mainly using pots but also gillnets) providing them more secured revenues.

We also found that vessels tend to change fleet and start or stop their activity quite often, meaning that the barriers between the pelagic and coastal fleets but also between the active and inactive were very porous. This result differs from Marchal and Vermard (2013) who found, in other fisheries contexts, that historical fishing effort was a significant factor in explaining current fishing effort allocation. This higher mobility within the Guadeloupe fleet could be explained by the local context with i) multipurpose small-scale vessels having the possibility to switch rapidly from fishery to another and ii) a significant number of vessels with low fishing activity moving from active to inactive vessel status from year to another. Conversely, mobility is weakly explained by flows on the vessels second-hand market. Transaction rates within the Guadeloupe fleet were low (2.2% on average) compared to 10% in France mainland fisheries (Van Putten et al., 2012). This means that the second-hand market was not a key element for entering the activity or changing fishery. This can be explained by the fact that, contrary to France mainland, there was no real limitation on the number of permits for building new vessels over the period (Guyader et al. 2022). As there is no formal license system per fishery with a *numerus clausus* (Guyader et al. 2019), it is also not necessary to buy a second-hand vessel and the associated license to enter a fishery, being coastal or pelagic.

However, access to the MFADs fishery was, in fact, constrained and this may explain the decline in the pelagic fleet and the difficulties in renewing vessel-owners' generations. As mentioned by Guyader et al., (2018), exclusive territories linked to the installation of private MFADs made the space available for fishers who did not own MFADs mechanically reduced. Indeed, private MFADs were moored by fishers following virtual lines from the harbours with MFADs anchored from 5 up to 45 naut. miles offshore, at a few degrees distance from the neighbouring (Guyader et al., 2018). There were as many lines as fishing vessels using MFADs with 1 to 40 MFADs or more per track line, these lines being defended by their "owners". Almost all of the space is occupied within a 45 naut. miles radius of Guadeloupe leaving few possibilities for newcomers —young vessel owners willing to enter the pelagic fishery or established coastal fishers— to set their own MFADs or to operate on other fishers' MFADs. Many conflicts were reported between MFADs owners and between MFADs owners and non-owners (Guyader et al., 2018). As mentioned by Said et al. (2021), newcomers, especially young fishers, were forced to set their MFADs in the offshore areas, beyond 45 naut. miles. This means higher setting and exploitation costs due to sea-depth and distance from the coast, creating more financial and operational pressure on the younger generations who need to spend longer time and more fuel to reach their MFAD "territories". The increased density of MFADs also made it more difficult for trolling (LTL) fishers to target pelagic species. Indeed, trolling fishers needed to avoid the MFADs to avoid the potential risk of conflicts with their owners but with a smaller chance to get the schools that tend to gather around MFADs. The result is that most of the trolling fishers left the pelagic fishery to become inactive or to enter the coastal fishery.

A recent study has confirmed that the harvesting of large pelagic species with MFADs still generated more income than the harvesting of coastal resources but that economic rent could be dissipated by an increase in vessels harvesting costs but also the excess number of MFADs in the fishery (Guyader et al. 2022). As fishing operation were organised based on very fuel intensive daily trips, the use of vessels that could operate for several days seems to be, as in Martinique (a neighbour French island), an interesting prospect for reducing vessel costs and make the pelagic fishery still more profitable than the coastal fishery. This development is undoubtedly necessary but not sufficient. From stakeholder interviews including fishers, Guyader et al. (2022) also reported the need to better regulate through a management plan the number of MFADs by setting MFADs quota per vessel, to set up collective MFADs and to establish an official licensing system for MFADs fishing to secure access to new entrants and in particular to young people wishing to invest in the pelagic fishery. Without such measures, the Guadeloupe fleet will probably die of attrition in the next 10-20 years. Even if small-scale MFADs fisheries in the insular Caribbean are heterogeneous (Wilson 2020), fisheries operate in a relatively unregulated and data-poor context, raising concerns about their long-term socioeconomic and biological sustainability supporting that expected benefits of MFAD fisheries will not be achieved without improved governance and management frameworks (Vallès 2023)

6 Conclusion

The application of the stock-flow approach by the Guadeloupe small-scale fleet and sub-fleets including vessel owners combined with an analysis of the evolution of the fishing effort made it possible both to disentangle the main trends concerning the decline of the fleet and the movements between pelagic and coastal fleets over the last decade. We showed that MFADs fisheries had positive effect in terms of fishery attractiveness compared to coastal fisheries for the youngest vessel-owners, but that the conditions of attractiveness strongly depend on the way theses fisheries are managed. The lack or absence of a management plan including an MFAD license and MFADs regulation can undermine the potential benefits of MFADs but can also generate conflicts between fishers and equity issues between generations.

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