

# Coriolis Fuel Mass Flow Metering for Fishing Vessels

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**Abstract** — A fuel monitoring system has been tested on two boats of semi-pelagic pair trawlers in the Central Adriatic Sea. The system named *CorFu* meter (*CorFu-m*), conceived at CNR-ISMAR Ancona (Italy), consists of two mass flow sensors, one Multi Channel Recorder and one GPS data logger. The range of the engine power of the selected vessels is 1000-1200 HP, with  $L_{OA}$  of around 25-35 m. Both vessels work with a gear of similar design and size, the differences between the two vessels are in the propeller design and the hull material: the first with a controllable pitch and a metal hull, the second with a fixed pitch and a wooden hull. A typical commercial round trip for a semi-pelagic trawler consists of several fishing operations (steaming, trawling sailing, etc.). The working time duration, the vessel speed, the total fuel consumption and the instant fuel rate were logged by the system. Fuel consumption rate [l/h] and vessel speed [kn] data were used to identify fuel consumption under different vessel-operating conditions. The highest fuel demands were during the trawling (130 l/h at 4.4 kn) and the steaming (100-130 l/h at 11 kn) phases. Fuel savings of up to 15% were obtained by bringing the navigation speed close to the best running point.

**Keywords:** Fuel saving; energy efficiency; fishing; pair-boat trawling; Mediterranean semi-pelagic fisheries.

## I. INTRODUCTION

Fuel constitutes a substantial component of the cost of fishing. Energy saving has been a subject of research since the 1970s oil crisis, leading to several studies aimed at improving vessel design and power consumption. Recent oil price increases have brought renewed attention to energy-saving methods in the fishing industry [1], including the use of alternative fuels and lubricants (such as bio-diesel and bio-lubricants). However, due to the European Commission restrictions on new constructions, the major opportunities for reducing fuel consumption are chiefly related to improving vessel operation rather than commissioning new energy-saving vessels [2]. Additionally simple changes at the trawl level (such as steeper cuttings in the wings and bellies, and mesh size increases in the respective net sections) demonstrated a potential fuel reduction of up to 18-20% ([3], [4], [5], [6]).

The work described in this paper forms an integral part of a series of studies undertaken by the CNR-ISMAR of Ancona (Italy) during the European Project ESIF (EU FISH/2006/17 LOT3) to investigate the means of reducing energy expenditure in trawl fishing. The actual proportion varies between fisheries, but can reach up to 50-60% in cases such as the commercial bottom trawling or semi-pelagic fishery (*volante* trawl, in Italian). Anchovy (*Engraulis encrasicolus* L.) is the main target species for the Italian semi-pelagic fishing fleet and represents 90% of the total catch in the Adriatic Sea and 24% of the total Mediterranean catch ([7], [8]). The value of Adriatic anchovy landed catches was estimated at about 35 MECU in 1998. The same fishing gear catches anchovy and also sardine (*Sardina pilchardus* Walb.) and to a lesser extent other pelagic fish such as sprat (*Sprattus sprattus* L.), horse mackerel (*Trachurus* spp.) and mackerel (*Scomber* spp.).

The *volante* is mainly used in the Northern and Central Adriatic. At present approximately 70 couples of fishing vessels use this gear; but there are wide variations in size and engine power. In the *volante* trawl fisheries special attention might be given to vessel operations because the choice of the best running points (i.e. speed, RPM, pitch, etc.) could maximize cash flow, both in trawling and in navigation. Such operating choices are a major contribution toward energy saving and must be continuously adjusted according to vessel requirements. The main objective of this study was to identify the potential for fuel-savings in the pelagic trawlers by improving the vessel's operating conditions. Semi-pelagic trawlers were chosen for the study since they spend most of their time searching for schools of fish and sailing to- and from the fishing grounds.

## II. MATERIAL AND METHODS

### A. Data collection and metering devices

The data collecting system consisted of three principal components: one GPS data logger, two mass flow sensors and one multi channel recorder. In the current experiment, besides collecting fuel consumption (mass flow), geo-referenced

positions, speed all by haul, we also included data collection of catches per haul. For this purpose, a paper logbook was developed in accordance with the fishermen, in order to minimize the impact on the normal fishing operations.

The skipper registered catches per haul such as quantity of commercial catch and species composition and some other technical parameters: RPM of the main engine, course [°], bottom depth [m], length of trawling warps [m]. The GPS logger unit does not include an in-vehicle display (Figure 1), it recorded on a compact flash memory: latitude, longitude and speed at a rate of 1 second. The unit comprised a data logger and an 8-channel GPS receiver connected with an external antenna. The two mass flow sensors are two *Coriolis* Mass Flow sensors (Figure 1).



Figure 1. *CorFu-m* system mounted onboard the monitored semi-pelagic fishing vessels: (a) mass flow sensors for the measurement of fuel consumption; (b) multi channel recorder mounted on the vessel's bridge for the visualization of the fuel consumption; (c) GPS data logger.

They allowed the measurement of different variables such as mass, density and volume of fuel. The basic principle of the *Coriolis* measurement does not rely on the physical properties of the fluid such as viscosity and density. The mass flow sensors were positioned before and after the main vessel engine, in order to have an accurate measurement of both the instant- and total fuel consumption. Both flow sensors were connected to a Multi Channel Recorder (Figure 1), which showed the skipper the actual fuel consumption rate [ $l/h$ ] as well as the total fuel consumption [ $l$ ]. Data were stored at a rate of 1 second on a compact flash memory and were periodically downloaded on a personal computer for the following data elaboration. A more detailed description of the data analysis is given in [9].



Figure 2. Mediterranean semi-pelagic pair-boat trawling.

### B. Monitored vessels

The *CorFu-m* data monitoring systems were installed on two fishing boats named in the current paper with the acronyms PB01-NA and PB02-AM (Figure 2). The vessels belong to two different pair trawlers. The range of the engine power of the monitored vessels is 1000-1200 HP, with  $L_{OA}$  of 25-35 m. The general characteristics of the vessels were obtained from papers on board or from the Classification Society Register. Table 1 shows both the main characteristics of the vessel and of the main engine.

Both vessels work with gear of a similar design and size; the differences between the two vessels are in the propeller design and the hull material: PB02-AM with a fixed pitch and a wooden hull while PB01-NA has a controllable pitch and a metal hull (Table 1). The area usually covered by both the vessels, and the investigated area, spans over the entire Central Adriatic Sea.

Table 1. Characteristics of the two monitored vessels.

Vessel's characteristics		PB01-NA	PB02-AM
Type of fishing	-	Pelagic trawling	Pelagic trawling
Length overall [m]	$L_{OA}$	27.00	28.95
Length between perpendiculars [m]	$L_{BP}$	20.55	24.32
Beam [m]	B	7.00	6.86
Gross Registered Tonnage	GRT	104.12	117.71
Net Registered Tonnage	NRT	37.23	-
Gross International Tonnage	GT	139	112
Net International Tonnage	NT	41	-
<b>Main engine characteristics</b>			
Builder	-	Yanmar	Mitsubishi
Engine power [kW]	P	809	940
Engine power [HP]	P	1114	1294
Propeller design	-	Controllable pitch	Fixed pitch
Crew	E	7	7

### C. Fishing gear

The monitored vessels operate in pairs with another two boats having similar characteristics. The fishing gear used was a typical commercial Mediterranean semi-pelagic pair-boat trawl, it is usually larger than the commercial bottom trawls, where the mean length from the wings to the codend is about 60-70 m (Table 2). The front parts are usually made with large meshes (ropes are not widely used), which have the of aim herding the target pelagic schools. The horizontal net opening is maintained by two boats towing the net. Floats on the headline and weights on the groundrope maintain the vertical net opening.

Two big weights (around 300 kg each) are joined to the end of the lower wings in order to keep the groundrope deep. Modern large midwater trawls, however, are rigged in such a way that floats are not required, because the downward forces of the two weights keep the vertical net opening during fishing.

Table 2. Main characteristics of the Mediterranean semi-pelagic pair-boat fishing gears.

Item	Value
Gear code	OTM (24-40 m)
Otter boards	No otterboards used
Main gear dimensions (circumference, beam width)	Fishing circle: around 280 m (400-450 meshes; 600-650 mm of mesh size)
Headline- and footrope-length	60-65 m
Siderope length	30-35 m
Legal codend mesh size	20 mm

### III. RESULTS

#### A. Description of the different fishing operations

A typical round trip for a semi-pelagic trawler consists of several operating situations for different engine loadings, we characterized some important operations as reported in Table 3. The performance of both the monitored vessels (PB01-NA and PB02-AM) was evaluated during the different operations of a typical fishing trip (Table 4). This allowed for a full characterization of the average trip for each vessel (Figure 3 and Figure 4).

For both the vessels, the time spent in sailing and searching of schools (SSS) averages for 51-54% of the daily commercial trip (40-45% for sailing and 9-11% for searching), while the time spent in trawling is just 24-27% then it is relatively low when compared to navigation.

As such, the fuel rate in navigation at 10 kn will be around 83 [l/hr] and 91 [l/hr] for the PB01-NA and PB02-AM respectively (Table 4). The duration of the SSS phase depends on the time spent finding the schools of fish. After a shoal is spotted on the sonar and after the gear setting, we have identified a phase named gear shooting (SHO), it is usually at a low speed regime (5.0-5.5 kn) while the fuel consumption reaches about 80 l/h. At the end of the shooting phase, the trawling (TRA) starts. The trawling speed is usually around 4-5 kn, and we have the highest fuel demand of the fishing trip, which is around 120-140 l/h. The high variability of fuel consumption during the trawling phase (Figure 3 and Figure 4) is because semi-pelagic vessels usually operate at two different RPM conditions: lower RPM in shallow water and higher RPM in deeper waters. During this phase the values remain more or less constant for all the duration of the haul (typically about 45 minutes). Afterwards the speed is reduced to about zero: the cables are recovered (TCR) and the gear hauled (HAU). It is noteworthy that during TCR the fuel consumption is higher

than HAU because the vessels are thrust sternward and the main engine is kept at a low regime. The TCR and SHO are of medium energy-demanding with values between 40 and 100 l/h. While during the gear hauling operation (HAU), the vessel speed varies between 0 and 3 kn and we had a fuel consumption of about 20 l/h, that is the lowest value at engine idle speed.

Table 3. Main operations identified during a typical semi-pelagic commercial fishing trip.

Fishing operation	Acronym	Description
Sailing departing Sailing back Searching	SSS	<i>Sailing from the harbour to the fishing grounds; Sailing from the last fishing grounds to the harbour; Sailing between the fishing grounds: searching of the schools (variable speed).</i>
Shooting	SHO	<i>Shooting the gear at sea, towing cables releasing.</i>
Trawling	TRA	<i>Trawling operations out and out.</i>
Hauling	HAL	<i>Gear hauling operations.</i>
Towing cable recovery	TCR	<i>Gear setting operations just before the gear shooting.</i>

Table 4. Mean (in bold) and Standard Deviation (in italics) fuel consumption FC and mean speed VS[kn] under different working conditions for the first (PB01-NA) and second (PB02-AM) monitored vessel.

	PB01-NA		PB02-AM	
	VS [kn]	FC [l/h]	VS [kn]	FC [l/h]
TRA	<b>4.41</b> <i>0.17</i>	<b>129.32</b> <i>8.92</i>	<b>4.40</b> <i>0.19</i>	<b>133.42</b> <i>7.69</i>
TCR	<b>2.38</b> <i>0.42</i>	<b>40.90</b> <i>11.02</i>	<b>1.81</b> <i>0.34</i>	<b>49.53</b> <i>11.10</i>
HAU	<b>1.37</b> <i>0.61</i>	<b>22.78</b> <i>6.09</i>	<b>1.42</b> <i>0.49</i>	<b>15.74</b> <i>2.09</i>
SHO	<b>5.16</b> <i>0.47</i>	<b>79.68</b> <i>8.92</i>	<b>5.50</b> <i>0.58</i>	<b>85.37</b> <i>8.97</i>
SSS <sup>(*)</sup>	<b>10.00</b>	<b>83.09</b>	<b>10.00</b>	<b>90.99</b>

<sup>(\*)</sup> mean calculated value at 10 kn of vessel speed.

Table 5 pertains the total fuel consumption per day (Q[l/day]), the variation strongly depend on the navigation (steaming and searching operations) phase. Here, other two indexes have been calculated: WFC[kg/l], which is the total catch of fish per litres of fuel and FCW[l/(kW·hr)], which is the litres of fuel per working hour per engine power installed. The objective of WFC is to give an efficiency index, we found that it varies between 2.907 and 2.296 [kg/l] for the PB01-NA and PB02-

AM respectively. It is higher in the first vessel showing a higher efficiency.  $FCW[l/(kW \cdot hr)]$  is a calculated index and we found it is fisheries-specific and in this fisheries it seems to vary around  $0.1[l/(hr \cdot kW)]$  (Table 5). Consequently it could be used to estimate the engine power installed for a generic given vessel knowing the daily fuel consumption and the working hours.

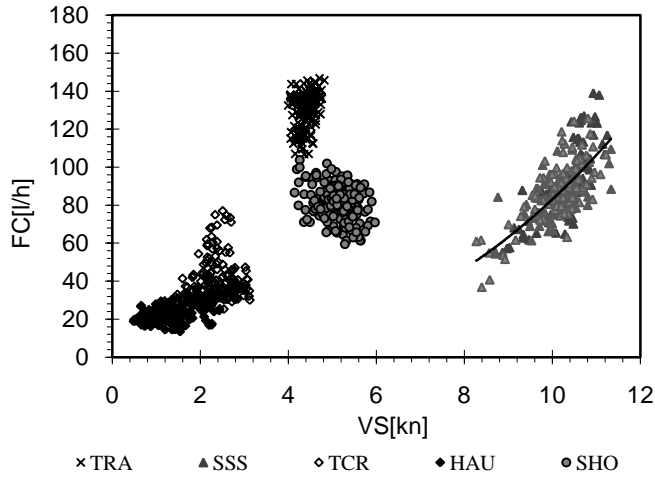


Figure 3. Monitored vessel PB01-NA. Fuel rate  $FC[l/hr]$  versus vessel speed  $VS[kn]$ , obtained during the main fishing operations.

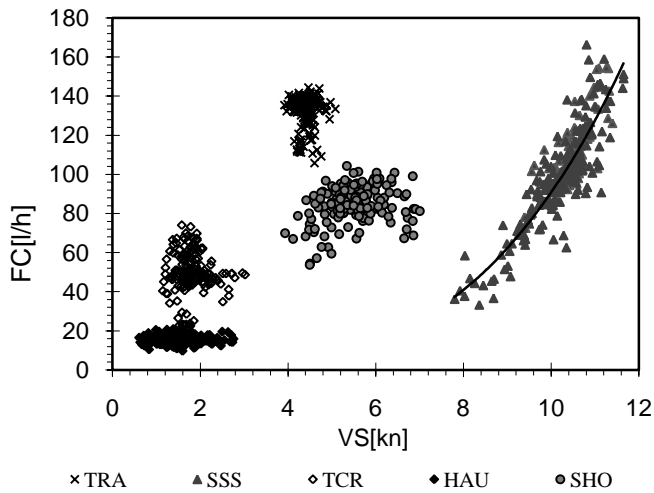


Figure 4. Monitored vessel PB02-AM. Fuel rate  $FC[l/hr]$  versus vessel speed  $VS[kn]$ , obtained during the main fishing operations.

### B. Fuel saving during the steaming condition

The fuel consumption ratio during the steaming condition at different vessel speeds was estimated and shown in Figure 5. Table 6 presents how in steaming conditions a reduction of just half a knot of vessel speed leads to a decrease in the fuel rate of up to 16%. A valuable outcome of this experiment was that, after having installed the fuel monitoring systems *CorFu-m* on board the two vessels, the skippers reduced the navigation speed of half a knot: from 11.0 kn to 10.5 kn,

leading to a significant improvement in fuel consumption in the short-term of about 12 and 17% respectively for PB01-NA and PB02-AM (Table 6 and Figure 6).

Table 5. Mean daily fuel consumption ( $Q[l/day]$ ) for both the monitored vessel PB01-NA and PB02-AM;  $WFC[kg/l]$ : total catch of fish per litres of fuel;  $FCW[l/(kW \cdot hr)]$ : litres of fuel per working hour per engine power installed. Mean (in bold) and Standard Deviation (in italics).

	PB01-NA	PB02-AM
<b><math>Q[l/day]</math></b>	<b>1142</b>	<b>1284</b>
	<i>136</i>	<i>180</i>
<b><math>WFC[kg/l]</math></b>	<b>2.907</b>	<b>2.296</b>
	<i>1.541</i>	<i>1.282</i>
<b><math>FCW[l/(kW \cdot hr)]</math></b>	<b>0.106</b>	<b>0.096</b>
	<i>0.007</i>	<i>0.010</i>

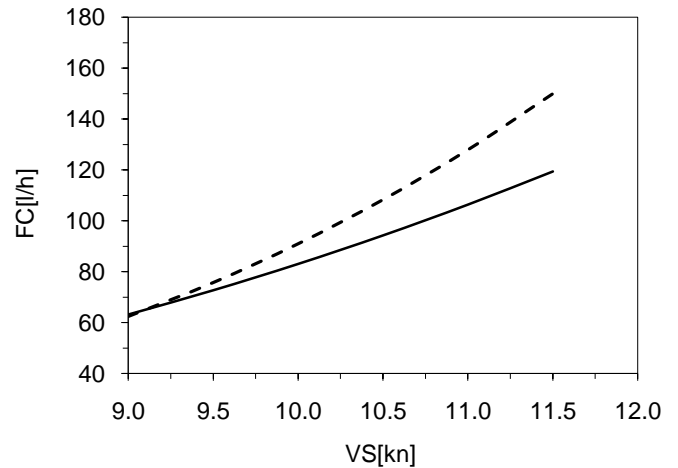


Figure 5. Estimated fuel consumption  $FC[l/hr]$  during the steaming and searching operations. PB01-NA: continues line; PB02-AM: dotted line.

Table 6. Operational parameter mean fuel rate  $FC[l/h]$  for both the monitored vessel PB01-NA and PB02-AM, obtained during the steaming condition (sailing, schools searching operations) through vessel speed  $VS[kn]$ .  $dFC[l/h]$  and  $dFC\%$  are the estimated fuel saving and the ratio of the fuel saving in percentage respectively.

$VS[kn]$	PB01-NA			PB02-AM		
	$FC[l/h]$	$dFC[l/h]$	$dFC\%$	$FC[l/h]$	$dFC[l/h]$	$dFC\%$
10.0	63.20	-	-	62.43	-	-
10.5	72.73	9.53	13.10%	75.75	13.31	17.58%
11.0	83.09	10.36	12.47%	90.99	15.25	16.76%
11.5	94.31	11.22	11.90%	108.34	17.34	16.01%
12.0	106.42	12.11	11.38%	127.94	19.60	15.32%

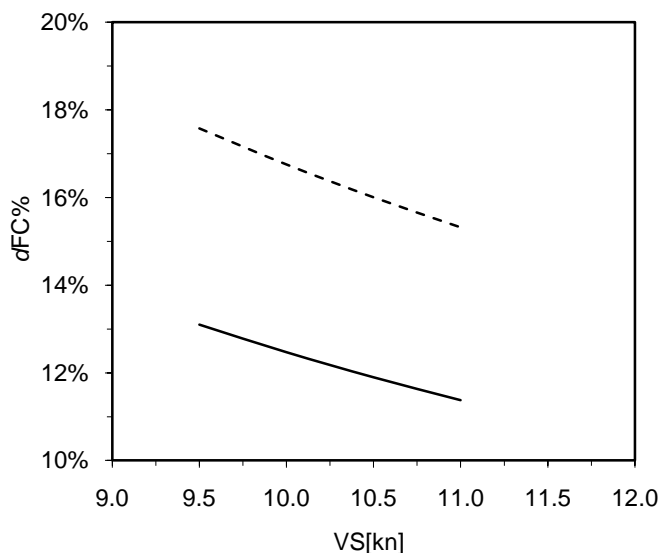


Figure 6. Estimated fuel saving in percentage  $dFC\%$  obtained during steaming and searching operations through vessel speed (VS[kn]). PB01-NA: continues line; PB02-AM: dotted line.

### C. Conclusions

The main objective of this study was to identify the potential for fuel-saving in the Mediterranean pelagic trawlers by improving vessel's operating conditions. Semi-pelagic trawlers were chosen for the study since they spend most of their time in searching the fish schools and steaming to- and fro- the fishing grounds. In this study we demonstrated that a significant improvement in fuel consumption could be obtained in the short-term for two Italian trawlers. A fuel monitoring system was tested on two semi-pelagic pair trawlers in the Central Adriatic Sea. The system named *CorFu* meter (*CorFu*-m), conceived at CNR-ISMAR Ancona (Italy), consists of two mass flow sensors, one Multi Channel Recorder and one GPS data logger. The financial investment for one complete *CorFu*-m system, which is made up of two mass flow sensors one Multi Channel Recorder, including the electrical and mechanical fittings with installation and system tests is estimated at 8 kEUR (mass flow sensors, Multi Channel Recorder, Electrical and Mechanical fittings). Fuel savings of up to 5-10% were obtained by bringing the navigation speed close to the best running point, which is the vessel's operating speed that maximizes efficiency. Assuming that the total catching power will not change, the payback time for such investment will be less than 18 months. This benefit could be obtained without the need of major changes in overall vessel technology.

On the contrary of the bottom trawling (see [3], [4], [5]), in the semi-pelagic fisheries we detected that the duration of the navigation phase varied substantially, since it depends heavily on the strategy adopted by the skipper (such as the distance from the coast and time spent navigating in the fishing grounds, as dictated by the abundance of target species).

Compared to the second vessel, the lower fuel consumption of the first vessel is essentially due to the different naval technology used. Gains in propulsive efficiency during free navigation might be attained using a controllable pitch instead of a fixed pitch propeller, which can permit an optimum combination of pitch ratio and propeller revolutions for each operating condition. Nevertheless, in the steaming conditions the different fuel consumption, also could have depended on different hull geometry and on the power engine installed. Finally considerable savings in fuel consumption have been obtained from this type of propeller by towing at lower speeds.

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