RESEARCH PAPER

Measurements of Fuel Consumption and Towing Resistance in Sea Snail Beam Trawl Fisheries: Preliminary Results

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Abstract

At constant speed and revolutions per minute (rpm), the effect of beam trawls on fuel consumption and towing resistance in sea snails (*Rapana venosa* Valenciennes, 1846) fisheries were measured by a fuel flow meter and force gauge. A traditional beam trawl was used to capture sea snails. Three different sledges (one traditional, T, and two modified, M-1 and M-2) were compared for differences of fuel consumption and towing resistance on two sea ground types (sandy and sandy&muddy) during the fishing operation. Beam trawls were observed by underwater video cameras. Trawl hauls with a 10 min towing duration were carried out from July to September 2015 in the southern Black Sea (Turkey). M-1 had the lowest fuel consumption on sandy bottoms and sandy&muddy bottoms at constant rpm and speed (P<0.0001). Although the other sledges (T and M-2) had low towing resistance in some cases, M-1 was found to be slightly better than the other sledges (P<0.0001).

Keywords: Sea snail beam trawl, fuel consumption, towing resistance, rapa whelk, Black Sea.

Introduction

Beam trawls for sea snail fishery have been employed in Samsun since 1980s (Knudsen, Zengin, & Koçak, 2010). The potential effects of active fishing gear (otter trawls, beam trawls etc.) on the marine ecosystem is a worldwide problem (Jones, 1992; Kaiser & Spencer, 1996; Engel & Kvitek, 1998; Rijnsdorp, Buys, Storbeck, & Visser, 1998; Valdemarsen, Jørgensen, & Engås, 2007; Currie & Parry, 1996; Collie, Escanero, & Valentine, 1997; Collie, Hall, Kaiser, & Poiner, 2000; Suuronen *et al*., 2012). Of these, the beam trawl is used mainly for species such as flatfish (Groenewold & Fonds, 2000) and shrimp (Gamito & Cabral, 2003; Zengin & Tosunoğlu, 2006) in European waters. The gear is also responsible for rubbing and cultivation of the sea bottom and the removal and destruction of some infaunal and epifaunal species (Groenewold & Fonds, 2000; Kaiser & Spencer, 1996; Rijnsdorp *et al*., 1998).

The environmental effects of towing gear (changes of seabed topography, penetration depth etc.) have been measured by various methods, such as acoustic tools, underwater cameras and load cells (Fonteyne, 1999). To measure seabed disturbance, the first experiments were conducted by the Council for the Exploration of the Sea in the 1970s, and then direct underwater observations by divers, cameras and acoustic devices were used by scientists (Walsh, Engäs, Ferro, Fonteyne, & van Marlen, 2002). In addition to studies of the environmental effects of beam trawls, discard mortality of beam trawls (Kaiser & Spencer, 1995), codend selectivity (Ateş *et al*., 2010; Zengin & Tosunoğlu, 2006) and gear modifications (Abookire & Rose, 2005; Suuronen *et al*., 2012), a small number of studies on energy saving and consumption (Sala, 2002; Schau, Ellingsen, Endal, & Aanondsen, 2009; van Marlen & Salz, 2010; Balash & Sterling, 2012; FAO, 2015) have been performed for towed gear.

Beam trawls have been identified as a gear towed from outrigger booms (EC, 356/2005). The horizontal opening of the net is provided by a rigid body (frame). A pair of shoes is welded to the ends of a metal beam so that it can slide over the sea bottom (Valdemarsen *et al*., 2007). In the Black Sea, traditional beam trawls, which is used in sea snail fisheries, with shoes welded on rigid frames have been used for sea snails since the 1980s. Sea snail beam trawls have 3 m mouths with 1 m codends in a 72 mm mesh size (Anonymous, 2016. Both shoes have claws to connect the steel wire, which have a penetration depth of 50–70 mm from one end to the

other. Samsun is the most important region for the sea snail fishery with the largest fishing fleet (>400 fishing vessels) (Zengin & Knudsen, 2006). However, fishing pressure on sea snails causes destructive environmental effects in the Black Sea. In 2015, 8795.3 tons of sea snails were captured in Turkish waters of the Black Sea. Of these, approximately 80% was obtained in the eastern Black Sea (TUİK, 2016). Fishing operations start from depths of 5–30 m (average 10 m) in the Black Sea (Zengin *et al.*, 2014).

Suuronen *et al.* (2012) stated that beam trawls are effective and practical for capture but that they are responsible for seabed deformations, have high fuel consumption and by-catch rates, need flat ground and are expensive for fishing. Fuel consumption depends on some essential factors, such as catch rate (Enerhau, Amble, & Karlsen,1993), towing speed (Beare & Machiels, 2012; Poos, Turenhout, van Oostenbrugge, & Rijnsdorp, 2013), fishing vessel (technology, engine etc.) and sea state, habitat type and gear type (Sala, De Carlo, Buglioni, & Luchetti, 2011a). Sala *et al.* (2011a) used mass flow sensors for the measurement of the fuel consumption of semi-pelagic trawlers during several fishing operations for different phases.

Poos *et al.* (2013) developed a model for testing the energy savings of beam trawls to find a correlation between towing speed, fuel consumption and catch. Beare and Machiels (2012) observed that increasing fuel prices force fishers to decrease average towing speed from year to year to reduce total fishing costs. In addition, if fuel prices rise continually, active fishing gear such as beam trawls may become uneconomical (Suuronen *et al.*, 2012).

In the study, we tested two modified and a traditional beam trawls by measuring the difference of fuel consumption and towing tension during the fishing operation. In addition, underwater recordings were made to observe physical impact of the gear on the seabed during capture.

Materials and Methods

Study Site and Fishing Gear

A total of 36 hauls were carried out on the commercial beam trawler (11.3 m length, 102.2 kW, 2600 rpm, max. speed ~9 knots, marinized diesel engine, Ford Cargo-1999) from July to September 2015 in the coastal water of Samsun in the southern Black Sea (Turkey) (Figure 1). In the study, 12 different experiments with a 10 min towing duration were performed with three replicates under constant rpm (1100 min^{-1}) and speed (2.4 knots) (Table 1). Revolutions per minute of diesel engine and fishing vessel speed were fixed manually by reading tachometer and GPS, respectively. All three replicates were the same direction with the dominant winds come from north. Fishing operations were conducted with the three types of beam trawls (traditional and modified gear) on commercial fishing grounds (sandy and sandy&muddy) at depths between 7.5 and 11.5 m.

We used a grab sampler for collecting surface sediments. Benthic materials were examined in the laboratory within the project of BENTHIS (EU-FP7-312008). The fishing gear was a traditional beam trawl with 200 meshes around the mouth (see Kaykaç, Zengin, Özcan-Akpınar, & Tosunoğlu, 2014 for technical details). The traditional beam trawl with shoes had steel wire stretching between the shoes at the mouth of the gear to scrape the sea bottom.

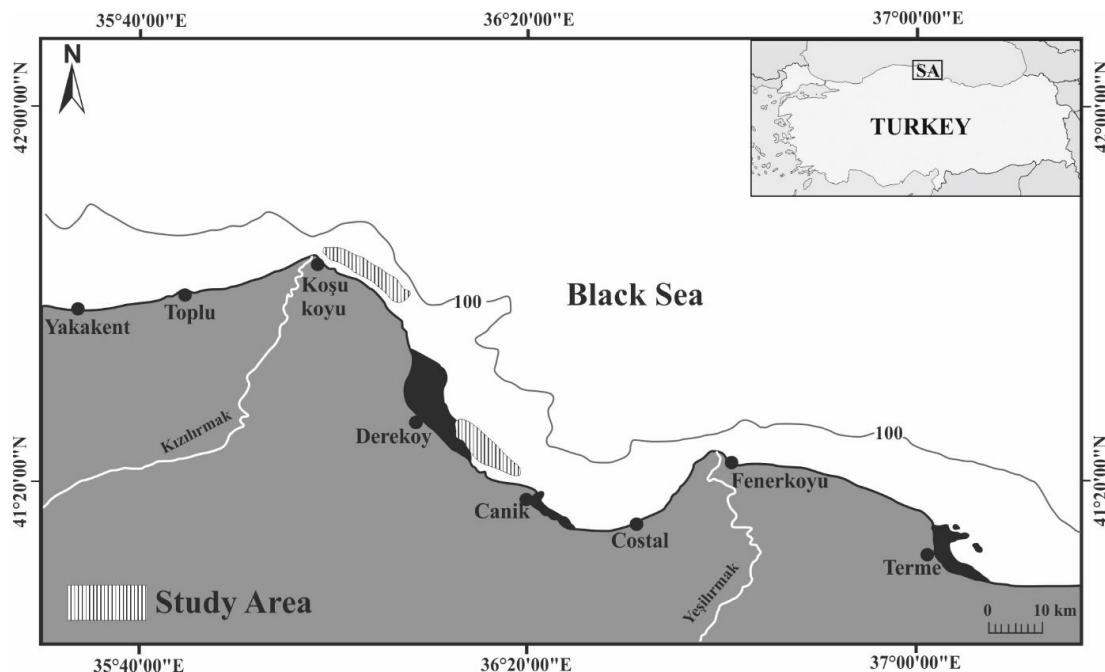In the study, different shoes (sledge) (T, M-1,

Figure 1. Study site.

and M-2) were used to determine the towing resistance and the difference of fuel consumption of the beam trawl. Modifications (two new sledge were designed) were made on the shoes of the traditional beam trawl to reduce physical impact of the gear on the seabed (Figure 2). Of these, the traditional beam trawl (T) with a small-size sledge had been used by local fishermen since the 1980s (Figure 2). In addition, three replicates were performed to determine the difference of fuel consumption of the beam trawls with wire between the shoes on the sandy ground. The weight of the sea snail beam trawls is 55 kg in air.

**Measurement of Fuel Consumption Difference**

An ultra-low flow (FLS-ULF01.H.0.2) sensor (fuel flow meter) was used to measure the flow of fuel consumption (l/h) (Figure 3). The flow rate range was between 1.5 and 100 l/h (±1%). Owing to it is known

that amount of fuel via return pipe to fuel tank for diesel engines, only the effect of sledge types of beam trawls on fuel consumption (DFC; l/h) was considered. So, the flow meter was installed horizontally between the fuel tank and the main engine with a pipe connection. The fuel flow meter with interface cable was supplied with electrical power from an on-board vehicle power source (<15 mA, 24 VDC-Voltage Direct Current). Measurements were performed for a 10 min duration at constant revolutions per minute (rpm, 1100 min^{-1}) or a constant speed (v) (vessel speed during fishing, 2.4 knots) on sandy and sandy&muddy ground (Table 1). Instantaneous fuel consumption (IFC; l/h) was recorded with 1 min intervals by reading the digital display of the flow meter and then average fuel consumption (AFC; l/h) was taken average from 10 measurements for three replicates of each experiment.

Table 1. Experiments for measurement of fuel consumption and towing resistance of beam trawls (36 hauls)

Exp.	Gear type			rpm (min^{-1})	v (knot)	Ground type	
	T	M-1	M-2	1100	2.4	SG	SGM
1	✓			✓		✓	
2		✓		✓		✓	
3			✓	✓		✓	
4	✓			✓			✓
5		✓		✓			✓
6			✓	✓			✓
7	✓				✓	✓	
8		✓			✓	✓	
9			✓		✓	✓	
10	✓				✓		✓
11		✓			✓		✓
12			✓		✓		✓

SG: Sandy ground, SMG: Sandy&muddy ground, v: Speed of fishing vessel, T: Traditional beam trawl, M-1 and M-2: Modified beam trawls
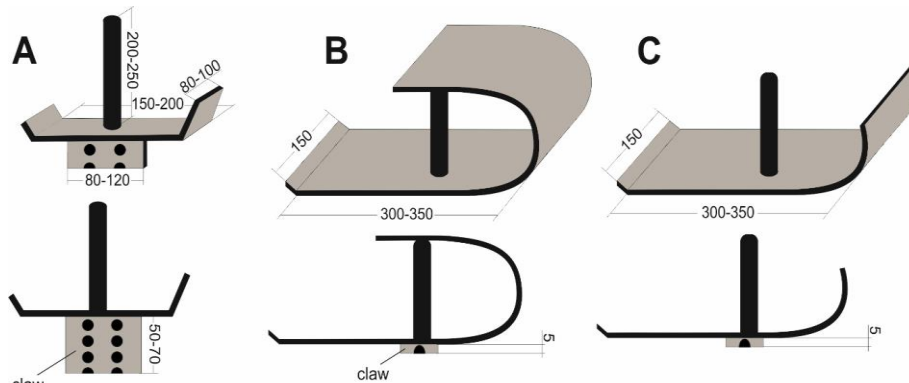
Figure 2. Shoe modifications of traditional beam trawl: **A)** Traditional shoe with 50–70 mm height of claw (T) **B)** Sledge-type shoe with 5-mm claw (M-1) **C)** Cutting sledge type with 5-mm claw (M-2).

Measurement of Towing Resistance

A force gauge with an S-type sensor (GERATECH, SH-50K, peak load value 50 kN, indication error: ±1%) was used to measure the tension (N) of the fishing gear's steel wire during the fishing operation (Figure 4). The measurements were taken for a 10-min duration at 1100 rpm or 2.4 knots on SG and SMG (Table 1). The force gauge was mounted on the steel wire (∅8, minimum breaking load; ~22.5 kN) of the beam trawl by connecting it with the steel shackle, thimble, carabineer and clips without cutting the wire. Data were transferred to the computer after the measurement.

Underwater Observations

The underwater observations were recorded by an underwater camera in the form of video clips. The digital camera (GoPro HERO4 Black Edition) with housing was mounted with plastic cable ties temporarily on the steel frame of the beam trawl at two different visual angles to monitor both the mouth of the net and the sledges. The recordings were transferred from the camera to the hard disk and captured to produce a picture using Video Capture Software.

Statistical Analysis

The statistical significance of the differences between the fuel consumption of beam trawls at constant rpm was determined with a one-way ANOVA. The difference between the fuel consumption of beam trawls at constant speed and the difference between the tensions of the wires of the
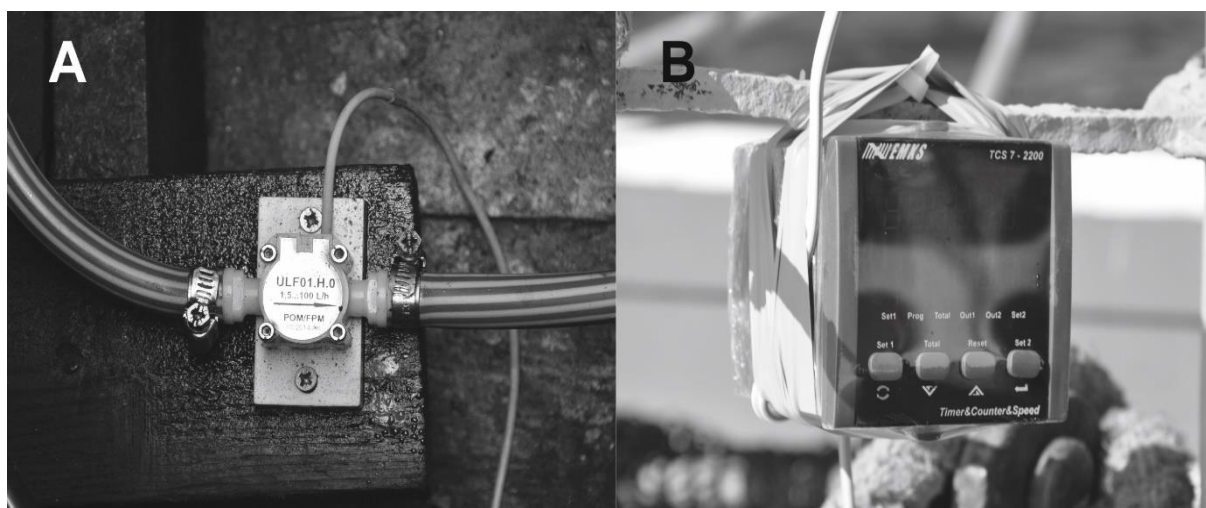
Figure 3. A) Installation of ultra-low flow (ULF) sensor and **B)** digital display.
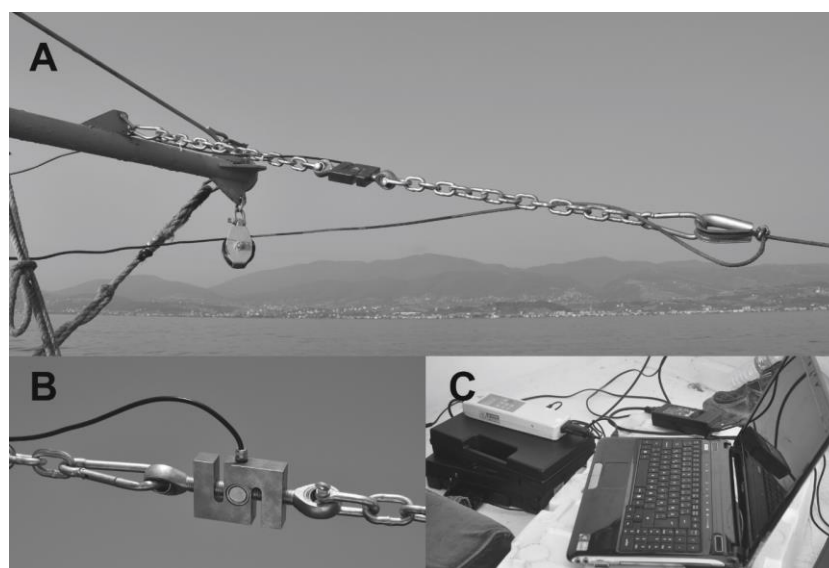
Figure 4. A-B) Installation of S-type sensor on steel wire of beam trawl and C) force gauge connection with computer.

three different beam trawls at constant rpm and speed was determined with a Kruskal–Wallis test.

Results

In total, 513.5 kg total catch was obtained during the experiments. Average catch was 14.3±2.07 kg. Statistically, there was no significant difference for total catch between the hauls ($P>0.005$).

Fuel Consumption Difference

The fuel consumption on sandy bottoms was lower than that on sandy&muddy bottoms for two experimental beam trawls (T and M-1). The difference was approximately 17% for T and M-1 at constant rpm. However, M-2 on mixed grounds had higher fuel consumption (3%) than it did on sandy grounds at constant rpm. Statistically, there was a significant difference between T, M-1 and M-2 according to the results of the experiments carried out on the sandy and sandy&muddy ground with constant rpm. M-1 had the lowest fuel consumption on the sandy ground ($P<0.0001$) and sandy&muddy ground ($P<0.0001$) at constant rpm (AFC_T: 3.26±0.23, AFC_{M-1}: 3.10±0.25, and AFC_{M-2}: 4.04±0.23 l/h on sandy ground and AFC_T: 3.93±0.19, AFC_{M-1}: 3.76±0.14, and AFC_{M-2}: 3.92±0.20 l/h on sandy&muddy ground, respectively).

Likewise, the other two beam trawls (T and M-1) had lower fuel consumption, which varied between 15.5% and 20.8%, on sandy grounds than sandy&muddy grounds at constant speed. The other experimental beam trawl (M-2) had almost the same consumption on both types of bottoms at constant speed. Statistically, the lowest fuel consumption was measured for M-1 at constant speed on both the sandy and sandy&muddy bottoms ($P<0.0001$) (AFC_T: 3.23±0.48, AFC_{M-1}: 3.21±0.55, and AFC_{M-2}: 3.84±0.15 l/h on sandy bottom and AFC_T: 4.08±0.19, AFC_{M-1}: 3.80±0.10, and AFC_{M-2}: 3.85±0.15 l/h on sandy&muddy bottom, respectively) (Table 2).

Towing Resistance

In the experiments, loads on warp were 0.87, 1.1 and 1.1 kN for T, M-1 and M-2, respectively on sandy bottoms at constant rpm. On sandy&muddy grounds at constant rpm, these values were 1.08, 0.90 and 1.27 kN, respectively. Statistically, at a constant 1100 rpm, while the lowest load was determined for T on sandy bottoms ($P<0.0001$), M-1 had the lowest tension on sandy&muddy bottoms ($P<0.0001$) (Figure 5).

At constant speed, M-2 had the lowest load (0.99 kN) on sandy grounds and M-1 had the lowest load (0.90 kN) on mixed bottoms, whereas T had high resistance (>1.1 kN) on both sea bottoms. On the sandy ground, it was determined that the lowest load was measured for M-2 at constant speed ($P<0.0001$) (Figure 6). M-1 had the lowest value on

Table 2. Measurement of fuel consumption difference of three different beam trawls working under various fishing conditions: AFC: Average fuel consumption (l/h); DFC: Difference of fuel consumption (arrows are representing the decrease and increase) for M-1 and M-2 with respect to T (%).

	Gear type								
	T		*M-1*			*M-2*			
	AFC	SD	AFC	SD	DFC	AFC	SD	DFC	
Sandy	3.26	0.23	3.10	0.25	↓4.9	4.04	0.23	↑23.9	*Constant rpm*
Sandy&muddy	3.93	0.19	3.76	0.14	↓4.3	3.92	0.20	↓0.3	
Sandy	3.23	0.48	3.21	0.55	↓0.6	3.84	0.15	↑18.8	*Constant speed*
Sandy&muddy	4.08	0.19	3.80	0.10	↓6.9	3.85	0.15	↓5.6	
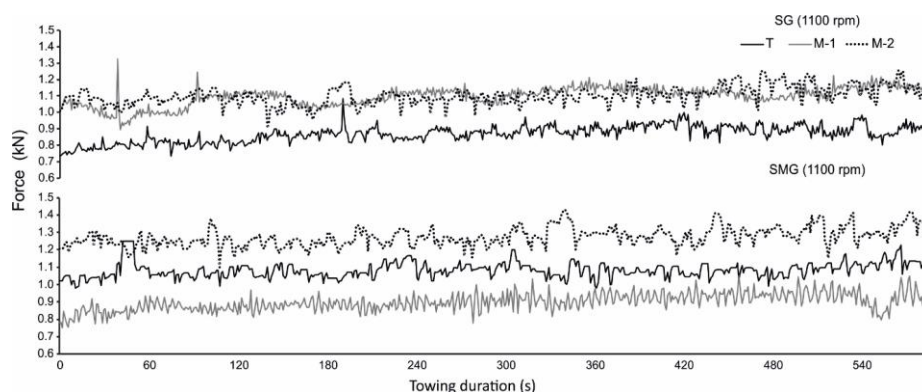
Figure 5. Measurements of force on beam trawls at 1100 rpm (SG: Sandy ground, SMG: Sandy-muddy ground, T: Traditional beam trawl, M-1 and M-2: Modified beam trawls).

sandy&muddy bottoms at constant speed (P<0.0001). According to the results, M-1 had the best average in terms of low fuel consumption and resistance during fishing operation.

Monitoring

It was observed that sledges of traditional beam trawls sometimes get up off the ground up to 20 cm. Mostly, traditional beam trawls, which are towed on claws, penetrate at least 5 cm into the sediment. The bottom surface of the sledge of a beam trawl does not completely contact the ground due to the penetration of the claw. Underwater observations showed that the sledge of the modified beam trawl (M-1) stayed stable and slipped on the ground properly. The other modified sledge (M-2) stayed on the bottom or was partly buried in the sediment. In addition, excluding the front of a sledge old M-2, the other parts of the sledge were covered by sediment (Figure 7).

Discussion

In the study, we used a force gauge and underwater camera to observe the load on warp and penetration of sledges into the seabed during capture. Therefore, we modified the sledges of beam trawls to decrease resistance to ensure both low fuel consumption and reduced destruction of the seabed.

Investigations have focused on the relation of fuel consumption and fishing vessel speed to identify energy performance under various operating conditions (Sala, Notti, & Virgilli, 2011b). Energy performance is generally associated with fishing gear
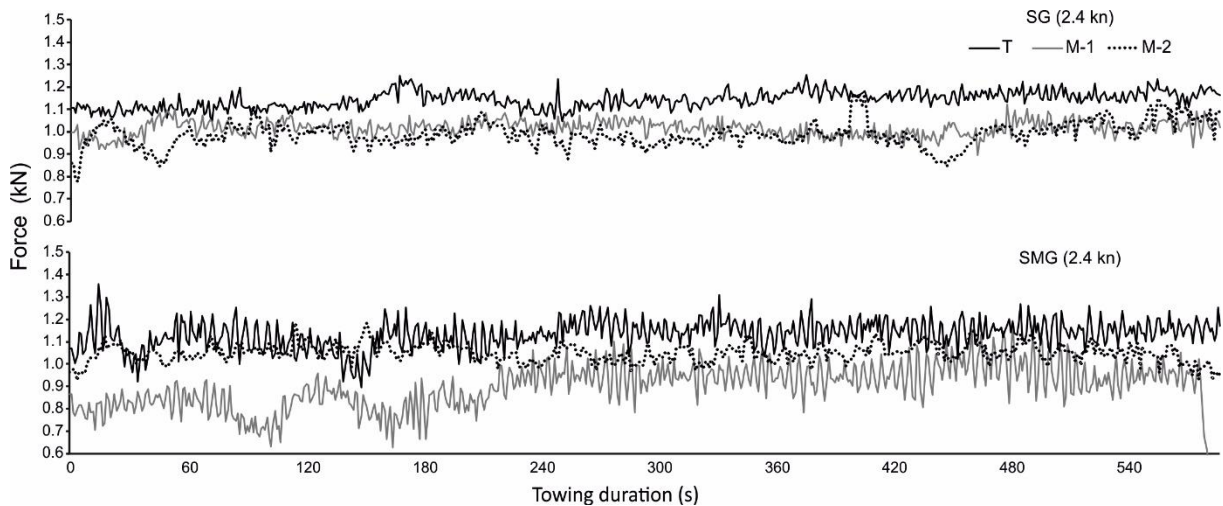
Figure 6. Measurements of force on beam trawls at 2.4 knots (SG: Sandy ground, SMG: Sandy-muddy ground, T: Traditional beam trawl, M-1 and M-2: Modified beam trawls).
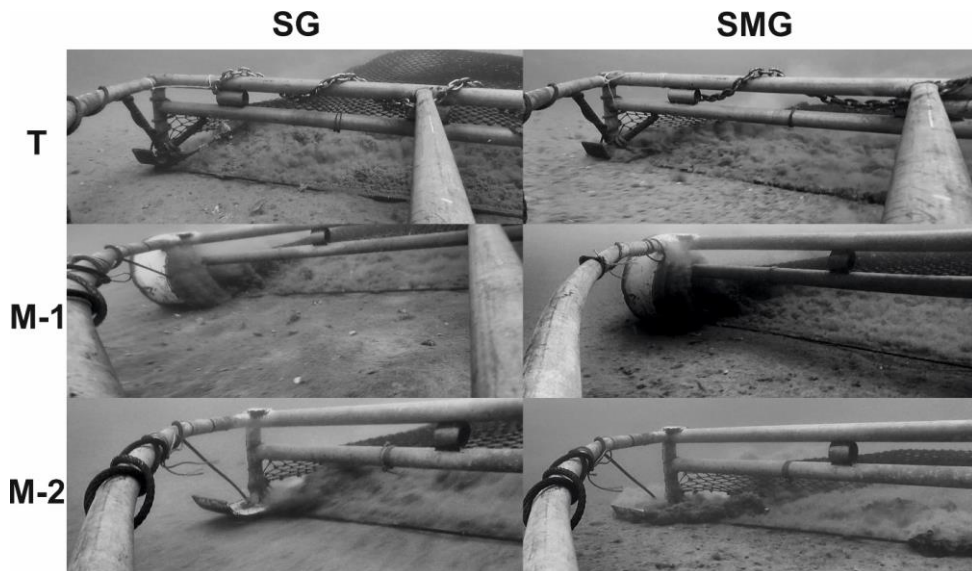
Figure 7. Underwater observations of sea snail beam trawls (T: Traditional beam trawl, M-1 and M-2: Modified beam trawls, SG: Sandy ground, SMG: Sandy&muddy ground).

and operation, sea conditions and properties of fishing vessels (Sala, 2002; Sala *et al*., 2011a; Notti, Sala, Martinsohn, & Damalas, 2012; Gabiña *et al*., 2016). Fuel consumption is a major factor effecting energy performance and depending on catch rate, vessel speed and technology, sea conditions, fishing field and gear (Enerhaug *et al*., 1993; Sala *et al*., 2011a; Beare & Machiels, 2012; Poos *et al*., 2013). In this framework, we measured average fuel consumption (at constant speed and rpm) to identify the effect of fishing gears on fuel consumption, as previous studies showed that increasing towing speed increases fuel consumption and total cost during capture (Beare & Machiels, 2012; Suuronen *et al*., 2012; Poos *et al*., 2013).

In the study, we fixed the vessel speed at 2.4 knots and also 1100 rpm due to the fishing operation speed varies from 2–2.5 knots for the capture of sea snails in that region. Table 2 shows, at constant rpm, M-1 caused lower consumption ranging between 4.3-4.9% than T on sandy and sandy&muddy grounds. In the M-2 experiments, fuel consumption was higher (23.9%) than T on sandy ground. The consumption appeared to decrease with 0.3% on sandy&muddy ground, however, statically the difference between T and M-2 was insignificant. Same results were observed for both modified beam trawls at constant speed. This inconsistency may have occurred as a result of the characteristics of bottom type and the sledge design of M-2 influencing to hydrodynamic behaviour. Sala *et al*. (2011a) reported that major factors affecting the fuel consumption were bottom type and fishing gears.

Measurement of the tension of the fishing gear's steel during the fishing operation is a simple way to assess the impact and the fuel consumption (Sala *et al*., 2011b). However, there are critical problems of assessing energy performance onboard fishing vessel due to uncontrolled conditions (Gabiña *et al*., 2016). In the study, the lowest load was 0.87 kN on sandy bottom for T and 0.90 kN on sandy&muddy bottom for M-1 at constant rpm. However, larger loads increase fuel consumption, the results were different than we excepted. The uncertainties could have been caused by uncontrolled sea conditions such as current and wind speeds, the behaviours of fishing gear during the capture (Sala *et al*., 2011b; Gabiña *et al*., 2016). At constant speed, T had higher resistance than modified beam trawls on sandy and sandy&muddy bottoms. Figure 5 and 6 show that data of loads on steel wire, which were recorded by force gauge, peaked at larger ranges on sandy&muddy grounds than sandy grounds at both constant rpm and towing speed. The fluctuation of load might be caused by fine sediment, where hold and release the fishing gear during the capture.

Researchers have used handheld video and underwater camera systems mounted on fishing gear to assess the seabed disturbances caused by towing gear (Currie & Parry, 1996; Smith, Papadopoulou, &

Diliberto, 2000). In some cases, divers have counted and measured seabed deformations after the fishing (Currie & Parry, 1996). In this study, we used two underwater camera systems to observe the effects of the beam trawls on the seabed during the fishing operation. In most cases, underwater observations showed that M-1 stayed stable and slipped, particularly on soft bottoms, properly due to the design of the sledge and the low resistance during the fishing operation. However, the sledges of the traditional beam trawl (T) were observed to be unstable. On the other hand, we found that when the sledges of M-2 were towed, they created resistance on the ground. The shape of sledges that are unsuitable for hydrodynamic environments may cause resistance and distributed sediment during operation.

In our experiments, sledge shape and sediment type were the main factors influencing the behaviour of fishing gear during the fishing operation. Finally, we determined that M-1, which is the one of the modified sea snail beam trawls, was the most appropriate gear to reduce resistance and fuel consumption on both sea bottoms at constant rpm and towing speed. We did not measure the fuel consumption of fishing vessel during the fishing operation, on the other hand we could conclude that the most appropriate design of sledge was M-1 by determining only the difference of fuel consumption between beam trawls.

Until now, an assessment of the fuel consumption and towing resistance of beam trawls has not been conducted in the Turkish Seas. The experiment did have some challenges, particularly with respect to measuring fuel consumption of fishing vessel, the correlation of fuel consumption and wire loads and a number of trials. However, we state that these preliminary results help fishing gear designers to understand the effects of the beam trawls on the seabed. In future, the size and shape of sledges and the use of beam trawls without steel wire stretching between the shoes and with lightweight constructions should be studied to mitigate the environmental effects of fishing gear, reduce carbon emissions and sustain sea snail fishery.

Acknowledgements

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