A Theoretical Approach to Determine the Total Resistance on Different Trawl Gears Used in Turkey

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ABSTRACT

The study aims to theoretically determine the total resistance forces acting on bottom trawls used in the commercial trawl fishery around the Turkish Peninsula. For this purpose, a total of 14 (2 for Black Sea, 2 for Sea of Marmara, 6 for Aegean Sea and 4 Mediterranean Sea) trawl gears were examined during the study representing all types of the bottom trawl fishery (e.g., fish targeted, shrimp targeted and mix) in Turkey. The calculation of the hydrodynamic forces of the gears was based on the determination of each gear component; net, floaters, sweep, door, warp and the friction force caused by footrope, sweep and door. The total resistance of trawl gears was calculated according to different towing speeds and warp lengths. Average resistance values of the examined nets with a 500 m warp length indicated that the frictional force of the trawl door composed more than 41.3% of the total resistance, followed by net (39.4%), both doors (6.3%), footrope friction (6.1%), sweep frictions (3.1%) and the rest belonged to sweeps, warps and floaters (totally 3.8%). It was determined that resistance caused by friction including sweeps, footrope and doors constituted more than 50% of the total resistance. Among the examined gears, the greatest resistance values were determined for the 600 meshes tailored-traditional Mediterranean type trawl gear.

Keywords: Bottom trawl, total resistance, friction, hydrodynamic

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INTRODUCTION

Trawls are one of the most important commercial fishing gears and account for almost a quarter of the global landed marine catch (Amoroso et al., 2018; Cashion et al., 2018). The target catch of trawl fishery is both demersal and pelagic species located in the water column. The gears are constituted by a set of the net, warp wire, trawl doors, sweeps, floaters, and sinkers. These elements should work well-matched with each other for good fishing performance. On the other hand, sea trials in order to understand the performance of these complex structures are expensive (Winger, DeLouche, & Legge, 2006). Therefore, mostly trawl performance studies were investigated by flume tank tests (Ferro, van Marlen, & Hansen, 1996; Balash,

2012), numerical modelling (Tsukrov, Eroshkin, Fredriksson, Swift, & Çelikol B, 2003; Lee, Lee, Cha, Kim, & Lee, 2005; Priour, 2009; Tang, Dong, Xu, Zhao, & Bi, 2017) analytical modelling (Park, 2007), software simulation (Lee et al., 2005; Priour, 2013). Numerical modelling and simulation, in particular, are becoming popular methods of evaluating trawl designs and assessing their performance during the early stages of gear development (Fiorentini, Sala, Hansen, Cosimi, & Palumbo, 2004).

The Turkish Peninsula is surrounded by different physicochemical and geological features which create particular species diversity and the catch composition of commercial fishery shows variety in each sea (Bilecenoğlu, Kaya, Cihangir, & Çiçek, 2014). More than 90% of de-

mersal fishes are landed by the trawl fishery in Turkey (Soykan, Akgül, & Kınacıgil, 2016). Trawls have a variety in size and types which are complex in their design, material choice, and construction. There are many scientific studies conducted on trawls, but most of them focused on selectivity (both size and species) (Aydın, Tokaç, Ulaş, Maktay, & Şensurat, 2011; Özbilgin, Tokaç, & Kaykaç, 2012; Tokaç, Herrmann, Aydın, Kaykaç, Ünlüler, & Gökce, 2014), discard characteristics (Soykan et al., 2016; Soykan, Bakır, & Kınacıgil, 2019), survival ratios (Düzbastılar et al., 2010) and other aspects of the demersal trawl fishery in Turkey (Stewart, 2002). On the other hand, scientific interest in resistance and other hydrodynamic effects is very limited and scarce in Turkey. Only Düzbastılar, Tosunoğlu, & Kaykaç (2003) calculated the resistance values of conventional and tailored demersal trawl nets. On the other hand, choosing the right size trawl according to the power of the vessel including the other components of the gear such as doors and footrope is crucial for fuel consumption and catch efficiency.

The study aims to be a theoretical approach to determine hydrodynamic effects on different trawl gears used in Turkey's commercial trawl fishery. The present work is the first theoretical study on the hydrodynamic forces on various types of bottom trawls considering the friction force and resistance of floaters for Turkey.

MATERIAL AND METHODS

Trawl gears

Resistance forces on trawl nets were well described by Fridman (1973) and Düzbastılar et al. (2003). Due to the lack of gear standardization in the Turkish trawl fishery, almost each trawler has its own trawl net design although there are some restrictions, especially on mesh size at the codend. Bottom trawls investigated for theoretical evaluation here have been used in commercial fishing around Turkey; the Black Sea, Sea of Marmara, Aegean Sea and the Mediterranean Sea. A total of 14 trawl nets (2 for the Black

sea, 2 for the Sea of Marmara, 6 for the Aegean Sea and 4 for the Mediterranean Sea) were examined during the study, and those were the representatives of each type of the bottom trawl fishery (e.g., fish targeted, shrimp targeted and mix) in Turkey. The nets emphasized in this study were chosen from published scientific papers around Turkish territorial waters (Table 1).

Total hydrodynamic resistance (R_T) was calculated by adding the resistance of each gear component; net, floaters, sweep, door, warp and the friction force caused by the footrope, sweep and door with the following formulae:

$$R_T = R_N + 2R_D + 2(R_S + R_W) + nR_F + F_F$$

R_T : Total resistance (N)

R_N : Net resistance (N)

R_D : Door resistance (N)

R_S : Sweep resistance (N)

R_W : Warp resistance (N)

n : Number of floaters

R_F : Floater resistance (N)

Friction forces consist of friction of the footrope, sweep and doors

$$F_F = F_{FF} + F_{FS} + F_{FD}$$

F_F : Friction forces

F_{FF} : Friction by footrope

F_{FS} : Friction by sweep

F_{FD} : Friction by doors

Table 1. General specifications of trawl nets evaluated in the study.

Code	Trawls types	Target species	Region	Literature
BS1	800 meshes	Fish	Black Sea	Özdemir et al., 2014
BS2	900 meshes tailored	Fish	Black Sea (Samsun)	Kaykaç et al., 2017
SM1	500 meshes traditional	Shrimp, fish	Sea of Marmara (Bandırma -Erdek)	Zengin et al., 2004
SM2	260 meshes tailored	Shrimp fish	Sea of Marmara (Tekirdağ-Şarköy, Hoşköy, Barbaros)	Zengin et al., 2004
AS1	900 meshes tailored	Fish	Aegean Sea (İzmir)	Tosunoğlu & Aydın, 2007
AS2	1200 meshes tailored	Shrimp, fish	Aegean Sea (İzmir)	Tosunoğlu & Aydın, 2007
AS3	1100 meshes tailored	Shrimp, fish	Aegean Sea (İzmir)	Aydın & Tosunoğlu, 2009
AS4	600 meshes tailored	Fish	Aegean Sea (Foça)	Tokaç et al., 2010
AS5	700 meshes traditional	Fish	Aegean Sea (Çanakkale)	Tokaç et al., 2010
AS6	600 meshes traditional	Fish	Aegean (Bodrum)	Tokaç et al., 2010
MS1	650 meshes traditional	Shrimps, fish	Mediterranean (İskenderun Bay)	Demirci et al., 2008
MS2	600 meshes tailored	Shrimp	Mediterranean (İskenderun Bay)	Demirci et al., 2008
MS3	500 meshes tailored-traditional	Fish	Mediterranean (İskenderun Bay)	Demirci et al., 2008
MS4	600 meshes tailored-traditional	Fish, shrimps	Mediterranean (Mersin Bay)	Özbilgin et al., 2018

Hydrodynamic resistance of trawl net

Trawl net sections in various sizes are composed of different materials. To estimate the hydrodynamic resistance forces, technical parameters such as rope diameter d (mm), the mesh length l (mm) and their ratio to each other (d/l) were taken from the technical plans. Metric characteristics of each section of the trawl nets were given in Table 2.

Resistance of the net (R_n) was calculated by the following formulas according to Nomura & Yamazaki (1975);

$$R_n = 25 \times \frac{d}{l} \times \lambda^2 \times v^2$$

R_n = Resistance of the net

$\frac{d}{l}$ = ratio between the diameter of net line and mesh length (mm)

λ = Length of the headrope (m)

v = Towing speed (ms^{-1})

Frictional resistance of footrope

The length, material and diameter of the footrope differed in each net (Table 3). Footrope weight in water was calculated with the following formulas:

Table 2. Metric characteristics of bottom trawl nets.

	P	M	d	l	d/l	N	RxN	L	B	h	a	A
BS1 Mean $d/l=0.025238$	1	1672	1.72	100	0.01720	2	0.03440	100	180	120	57.79	115.58
	2	1672	1.72	100	0.01720	2	0.03440	100	180	120	57.79	115.58
	3	836	0.86	40	0.02150	2	0.04300	400	400	225	61.92	123.84
	4		3	50	0.06000	1	0.06000	60	10	90	9.45	9.45
	5	836	0.86	40	0.02150	2	0.04300	400	400	225	61.92	123.84
	6		3	50	0.06000	1	0.06000	60	10	90	9.45	9.45
	7	836	0.86	40	0.02150	2	0.04300	600	600	180	74.30	148.61
	8	836	0.86	40	0.02150	2	0.04300	400	400	150	41.28	82.56
	9	836	0.86	40	0.02150	2	0.04300	300	300	180	37.15	74.30
BS2 Mean $d/l=0.01989$	1	1078	1.17	100	0.01170	2	0.02340	25	50	25	2.19	4.39
	2	1078	1.17	100	0.01170	2	0.02340	25	50	25	2.19	4.39
	3	1078	1.17	100	0.01170	2	0.02340	50	75	75	10.97	21.94
	4	1078	1.17	100	0.01170	2	0.02340	50	50	75	8.78	17.55
	5	923	1.08	44	0.02455	2	0.04909	150	187.5	75	12.03	24.06
	6	923	1.08	44	0.02455	2	0.04909	75	150	150	16.04	32.08
	7	923	1.08	44	0.02455	1	0.02455	525	450	175	81.08	81.08
	8	923	1.08	44	0.02455	1	0.02455	450	350	100	38.02	38.02
	9	923	1.08	44	0.02455	1	0.02455	450	350	100	38.02	38.02
	10	923	1.08	40	0.02700	2	0.05400	385	150	235	54.31	108.63
	11	1078	1.17	40	0.02925	2	0.05850	150	150	200	28.08	56.16
SM1 Mean $d/l=0.13318$	1	1030	1.20	80	0.01500	2	0.03000	15	15	24	0.69	1.38
	2	1030	1.20	80	0.01500	2	0.03000	15	15	24	0.69	1.38
	3	1030	1.20	80	0.01500	2	0.03000	25	25	32	1.54	3.07
	4	1030	1.20	80	0.01500	2	0.03000	25	25	32	1.54	3.07
	5	256	0.54	80	0.00675	2	0.01350	150	150	110	14.26	28.51
	6	256	0.54	80	0.00675	2	0.01350	150	150	110	14.26	28.51
	7	256	0.54	80	0.00675	2	0.01350	45	1	56	1.11	2.23
	8	256	0.54	80	0.00675	2	0.01350	45	1	28	0.56	1.11
	9	308	0.60	80	0.00750	2	0.01500	100	100	110	10.56	21.12
	10	462	0.74	20	0.03700	2	0.07400	75	70	120	2.58	5.15
	11	1030	1.20	80	0.01500	2	0.03000	50	50	25	2.40	4.80
SM2 Mean $d/l=0.020488$	1	925	1.08	80	0.01350	2	0.02700	1	9	20	0.17	0.35
	2	925	1.08	80	0.01350	2	0.02700	1	9	20	0.17	0.35
	3	642	0.89	60	0.01483	2	0.02967	12	40	92	2.55	5.11
	4	642	0.89	60	0.01483	2	0.02967	12	40	92	2.55	5.11
	5	308	0.60	24	0.02500	1	0.02500	110	1	125	2.00	2.00
	6	308	0.60	24	0.02500	2	0.05000	110	130	125	4.32	8.64
	7	308	0.60	24	0.02500	2	0.05000	110	130	125	4.32	8.64
	8	308	0.60	24	0.02500	2	0.05000	260	192	167	10.87	21.74
	9	308	0.60	24	0.02500	2	0.05000	192	175	146	7.72	15.43
	10	308	0.60	24	0.02500	2	0.05000	175	77	167	6.06	12.12
	11	308	0.60	28	0.02143	1	0.02143	66	66	100	2.22	2.22

Table 2. Continue.

	P	M	d	l	d/l	N	RxN	L	B	h	a	A
AS1 Mean d/l=0.020386	1	923	1.26	110	0.01145	2	0.02291	5	50	45	3.43	6.86
	2	923	1.26	110	0.01145	2	0.02291	5	50	45	3.43	6.86
	3	923	1.26	110	0.01145	2	0.02291	75	100	75	18.19	36.38
	4	923	1.26	110	0.01145	2	0.02291	50	50	75	10.40	20.79
	5	692	1.09	46	0.02370	2	0.04739	200	250	32,5	7.33	14.67
	6	692	1.09	46	0.02370	2	0.04739	100	100	100	10.03	20.06
	7	692	1.09	46	0.02370	2	0.04739	285	200	167,5	40.73	81.46
	8	692	1.09	46	0.02370	2	0.04739	100	150	32,5	4.07	8.15
	9	692	1.09	46	0.02370	2	0.04739	185	150	67,5	11.34	22.68
	10	692	1.09	46	0.02370	2	0.04739	350	250	100	30.08	60.17
	11	692	1.09	46	0.02370	2	0.04739	250	150	100	20.06	40.11
	12	692	1.09	46	0.02370	2	0.04739	150	150	100	15.04	30.08
	13		3.50	90	0.03889	1	0.03889	70	70	50	22.05	22.05
AS2 Mean d/l=0.019756	1	923	1.26	110	0.01145	2	0.02291	5	50	45	3.43	6.86
	2	923	1.26	110	0.01145	2	0.02291	5	50	45	3.43	6.86
	3	923	1.26	110	0.01145	2	0.02291	66,5	100	100	2308	46.15
	4	923	1.26	110	0.01145	2	0.02291	50	50	100	13.86	27.72
	5	692	1.09	46	0.02370	2	0.04739	200	250	100	22.56	45.13
	6	692	1.09	46	0.02370	2	0.04739	350	300	100	32.59	65.18
	7	692	1.09	46	0.02370	2	0.04739	100	200	200	30.08	60.17
	8	692	1.09	46	0.02370	2	0.04739	600	400	200	100.28	200.56
	9	692	1.09	46	0.02370	2	0.04739	400	200	200	60.17	120.34
	10	692	1.09	46	0.02370	2	0.04739	200	200	200	40.11	80.22
	11		3.50	90	0.03889	1	0.03889	70	70	100	44.10	44.10
AS3 Mean d/l=0.019664	1	692	1.09	95	0.01147	2	0.02295	5	50	45	2.56	5.13
	2	692	1.09	95	0.01147	2	0.02295	5	50	45	2.56	5.13
	3	692	1.09	95	0.01147	2	0.02295	66,5	100	100	17.24	34.48
	4	692	1.09	95	0.01147	2	0.02295	50	50	100	10.36	20.71
	5	615	1.02	44	0.02318	2	0.04636	200	225	75	14.31	28.61
	6	615	1.02	44	0.02318	2	0.04636	325	275	100	26.93	53.86
	7	615	1.02	44	0.02318	2	0.04636	100	175	175	21.60	43.20
	8	615	1.02	44	0.02318	2	0.04636	550	150	400	125.66	251.33
	9	615	1.02	44	0.02318	2	0.04636	150	150	200	26.93	53.86
	10		5.00	100	0.05000	1	0.05000	70	70	75	52.50	52.50
AS4 Mean d/l=0.05706	1		3,00	110	0.02727	2	0.05455	50	100	50	24.75	49.50
	2		3,00	64	0.04688	2	0.09375	1	50	50	4.90	9.79
	3		3,00	64	0.04688	2	0.09375	100	150	50	24.00	48.00
	4		3,00	56	0.05357	1	0.05357	250	200	100	75.60	75.60
	5		3,00	28	0.10714	1	0.10714	200	1	200	33.77	33.77
	6		3,00	56	0.05357	2	0.10714	100	100	100	33.60	67.20
	7		3,00	28	0.10714	2	0.21429	100	100	200	33.60	67.20
	8		3,00	44	0.06818	2	0.13636	100	100	150	39.60	79.20
	9		3,00	64	0.04688	1	0.04688	10	50	80	9.22	9.22
	10		3,00	64	0.04688	1	0.04688	10	50	80	9.22	9.22
	11		3,00	64	0.04688	1	0.04688	50	60	7	1.48	1.48
	12		3,00	64	0.04688	1	0.04688	50	60	7	1.48	1.48
	13		3,00	56	0.05357	1	0.05357	200	100	100	50.40	50.40
	14		3,00	48	0.06250	1	0.06250	100	1	100	14.54	14.54
	15		3,00	88	0.03409	1	0.03409	50	50	30	7.92	7.92

Table 2. Continue.

	P	M	d	l	d/l	N	RxN	L	B	h	a	A
AS5 Mean d/l=0.038943	1		5.25	100	0.05250	2	0.10500	35	110	108	82.22	164.43
	2		5.25	100	0.05250	2	0.10500	35	110	108	82.22	164.43
	3		0.54	100	0.00540	2	0.01080	150	150	107	17.33	34.67
	4		0.54	100	0.00540	2	0.01080	150	150	107	17.33	34.67
	5		2.50	100	0.02500	2	0.05000	43	15	45	6.53	13.05
	6		2.50	100	0.02500	2	0.05000	43	15	54	7.83	15.66
	7		2.50	80	0.03125	2	0.06250	20	20	123	9.84	19.68
	8		2.50	80	0.03125	2	0.06250	20	20	123	9.84	19.68
	9		3.00	44	0.06818	2	0.13636	250	250	163	107.58	215.16
	10		3.00	44	0.06818	2	0.13636	200	200	163	86.06	172.13
	11		3.00	44	0.06818	2	0.13636	100	100	163	43.03	86.06
	12		3.00	100	0.03000	1	0.03000	90	90	72	38.88	38.88
AS6 Mean d/l=0.048395	1		3.60	100	0.03600	2	0.07200	100	100	90	64.80	129.60
	2		3.60	100	0.03600	2	0.07200	100	100	90	64.80	129.60
	3		3.00	80	0.03750	2	0.07500	20	20	112	10.75	21.50
	4		3.00	80	0.03750	2	0.07500	20	20	112	10.75	21.50
	5		3.00	80	0.03750	2	0.07500	20	20	112	10.75	21.50
	6		3.00	80	0.03750	2	0.07500	30	30	112	16.13	32.26
	7		3.60	100	0.03600	2	0.07200	150	150	90	97.20	194.40
	8		3.60	100	0.03600	2	0.07200	150	150	90	97.20	194.40
	9		2.50	80	0.03125	2	0.06250	45	10	56	6.16	12.32
	10		3.00	80	0.03750	2	0.07500	50	15	67	10.45	20.90
	11		4.00	44	0.09091	2	0.18182	250	250	122	107.36	214.72
	12		4.00	44	0.09091	2	0.18182	200	200	102	71.81	143.62
	13		4.00	44	0.09091	2	0.18182	100	100	143	50.34	100.67
	14		3.00	84	0.03571	1	0.03571	100	100	74	37.30	37.30
MS1 Mean d/l=0.030825	1	1430	1.40	44	0.03182	2	0.06364	65	135	245	3.02	6.04
	2	1430	1.40	44	0.03182	2	0.06364	65	135	245	3.02	6.04
	3	1430	1.40	44	0.03182	2	0.06364	160	160	62	1.22	2.44
	4	1430	1.40	44	0.03182	2	0.06364	30	30	62	0.23	0.46
	5	1430	1.40	44	0.03182	2	0.06364	130	130	30	0.48	0.96
	6	1430	1.40	44	0.03182	2	0.06364	160	160	62	1.22	2.44
	7	1430	1.40	44	0.03182	2	0.06364	30	30	62	0.23	0.46
	8	1430	1.40	44	0.03182	2	0.06364	1	25	25	0.04	0.08
	9	1430	1.40	44	0.03182	2	0.06364	1	30	30	0.06	0.11
	10	1430	1.40	44	0.03182	2	0.06364	325	325	100	4.00	8.01
	11	1430	1.40	44	0.03182	2	0.06364	275	275	100	3.39	6.78
	12	1430	1.40	44	0.03182	2	0.06364	225	225	100	2.77	5.54
	13	1430	1.40	44	0.03182	2	0.06364	175	175	100	2.16	4.31
	14	1570	1.72	96	0.01792	2	0.03583	70	70	140	3.24	6.47
MS2 Mean d/l=0.03163	1	1430	1.40	50	0.02800	2	0.05600	1	133	300	28,14	56,28
	2	1430	1.40	50	0.02800	2	0.05600	1	110	300	23,31	46,62
	3	1430	1.40	50	0.02800	2	0.05600	143	143	40	8,01	16,02
	4	1430	1.40	50	0.02800	2	0.05600	76	76	320	34,05	68,10
	5	1430	1.40	36	0.03889	2	0,07778	360	100	200	46,37	92,74
	6	1430	1.40	36	0.03889	2	0,07778	100	100	200	20,16	40,32
MS3 Mean d/l=0.03026	1		4.00	96	0.04167	2	0.08333	17.5	112.5	131	65.40	130.79
	2		4.00	96	0.04167	2	0.08333	17.5	112.5	131	65.40	130.79
	3	1430	1.40	44	0.03182	2	0.06364	125	125	163	25.10	50.20
	4	1430	1.40	44	0.03182	2	0.06364	125	125	163	25.10	50.20
	5	1570	1.73	96	0.01802	2	0.03604	10	10	65	2.16	4.32

Table 2. Continue.

	P	M	d	l	d/l	N	RxN	L	B	h	a	A
Mean d/l=0.03026	6	1570	1.73	96	0.01802	2	0.03604	10	10	65	2.16	4.32
	7		4.00	96	0.04167	2	0.08333	35	15	47	9.02	18.05
	8	1570	1.73	96	0.01802	2	0.03604	10	10	38	1.26	2.52
	9	1430	1.40	44	0.03182	2	0.06364	250	250	61	18.79	37.58
	10	1430	1.40	44	0.03182	2	0.06364	200	200	41	10.10	20.20
	11	1430	1.40	44	0.03182	2	0.06364	150	150	245	45.28	90.55
	12	1570	1.73	88	0.01966	1	0.01966	70	70	120	25.58	25.58
MS4 Mean d/l=0.1276	1	1280	1.30	100	0.01300	2	0.02600	68	68	54.5	9.64	19.27
	2	1280	7.50	44	0.17045	2	0.34091	5	50	63.6	11.54	23.09
	3	1280	7.50	44	0.17045	2	0.34091	125	125	163	134.48	268.95
	4	1280	7.50	44	0.17045	2	0.34091	50	5	129.5	23.50	47.01
	5	1280	7.50	44	0.17045	1	0.17045	100	5	129.5	44.87	44.87
	6	1280	1.30	100	0.01300	2	0.02600	68	68	54.5	9.64	19.27
	7	1280	7.50	44	0.17045	2	0.34091	100	100	63.6	41.98	83.95
	8	1280	7.50	44	0.17045	2	0.34091	5	50	63.6	11.54	23.09
	9	1280	7.50	44	0.17045	2	0.34091	100	100	180	118.80	237.60
	10	1280	7.50	44	0.17045	1	0.17045	200	10	180	124.74	124.74
	11	1280	3.50	44	0.07955	1	0.07955	300	300	94	86.86	86.86
	12	1280	3.00	88	0.03409	1	0.03409	60	60	68.1	21.57	21.57

(S: Sections, M: Material T: Rtex values (twine thickness), d: Diameter (mm) of twine, l: Mesh size (mm), N: Number of each section, L: Number of meshes on the upper edge, B: Number of meshes on the lower edge, h: Number of longitudinal meshes, a: Twine surface area of each section (m²), A: Total twine surface area (m²) PA: Polyamide, PE: Polyethylene, PP: Polypropylene

$$F_B = \rho \times g \times V$$

$$F = m \times g$$

$$F_{Net} = F - F_B$$

Where;

$$F_B = \text{Buoyant force (N)}$$

$$\rho = \text{Density of sea water, } 1.026 \text{ (kgm}^{-3}\text{)}$$

$$g = \text{acceleration of gravity (ms}^{-2}\text{)}$$

$$V = \text{Volume of body submerged in fluid (m}^3\text{)}$$

In order to increase the impact of ground contact, additional weights have been applied on the footrope. Kaykaç, Zengin, Özcan-Akpınar, & Tosunoğlu (2014) stated the additional weight for Black Sea trawlers to be 100-150 kg. Considering this, a mean value of 1226.3 N (125 kg) additional weight was taken for Black Sea and Sea of Marmara. Özbilgin et al. (2018), reported that the average value of the additional weights on the footrope used in the Mediterranean as 1304.3 N (133 kg). Thus, we accepted this value in calculations for the Mediterranean. Due to lack of literature regarding additional weight on the footrope for the Aegean Sea, a total of 1471.5 N (150 kg) additional weight was accounted (personal communication with Aydın Kuruca, a net manufacturer and skipper). Total weight of footropes was calculated by adding the weights of footrope itself and the additional weight taking the floatation force of the material into account.

Hydrodynamic resistance of floaters

Floaters used in trawls are made of plastic materials, spherical shape ranging in different thickness values according to depth

Table 3. Parameters for calculating the total weight of footrope with respect to specifications of each net.

Net	Material	Diameter (mm)	Weight (kg) per 100 m	Length (m)	Weight in the air (kg)
BS1	PP	28	35.4	33.2	11.8
BS2	PP	32	46.3	35.4	16.4
SM1	PP	28	35.4	22.0	7.8
SM2	PP	28	35.4	18.6	6.6
AS1	PP	20	18.1	38.5	7.0
AS2	PP+PP	20+10	18.1+4.5	52.2	11.7
AS3	PP+PP	20+10	18.1+4.5	45.0	10.1
AS4	PA	30	55.5	29.6	16.4
AS5	COMB	18	48.8	32.0	15.6
AS6	COMB	36	60.3	28.5	17.2
MS1	PP	32	46.3	35.1	16.3
MS2	PP	28	48.4	35.8	17.3
MS3	PA	32	63.2	39.7	25.0
MS4	PA	28	106	20.3	21.5

PP: Polypropylene, PA: Polyamide, COMB: Combination

and pressure. The hydrodynamic resistance of floaters (R_F) was calculated by using Newton's model;

$$R_F = \frac{C_{df}}{2} \times \rho \times v^2 \times S_f$$

Where C_{Df} is the drag coefficient for a sphere, with a value of 0.47 (Fridman, 1969), ρ = density of sea water (1.026 g/cm³). Calculation of the floater's surface area (S_f) was considered as the sphere's projected area, the diametral circle (Pereira, 2012). Number of floaters during a trawl operation differs according to area and the target species. Mostly, a diameter of 20 cm spherical floaters were used around the Turkish Peninsula. While the number of those were taken to be 6 for the Black Sea and the Sea of Marmara, 10 for the Aegean Sea and the Mediterranean, based on the literature survey and the interviews with the skippers in each region (personal communication with Mustafa Kuraca and İsmail Öksüz who are the owner and the skipper of trawlers).

Resistance of sweep, door and warp

Auxiliary equipment such as sweep, doors and warp were kept constant in order to calculate hydrodynamic effects. Those were determined for different depths and towing speeds. Sweep was made of combined material (Polypropylene and lead) with a diameter of 32 mm, and it was assumed to be 200 m long in each gear. Weight per meter of the sweep was 8.83 N (0.9 kg) (personal communication with the rope manufacturer). Trawl doors (otter boards), evaluated in the study, have a rectangular shape, wooden material, surrounded by an iron frame, a surface area of 1,71 m² and a weight of 1.57 kN (160 kg), and the warp was made of steel wire with a diameter of 10 mm. Resistances of the sweep (R_s), the warp (R_w) and door (R_d) were calculated by the following formulas according to Nomura & Yamazaki (1975);

$$R_s = C_{Ds} / 2 \times \rho \times d_s \times L_s \times v^2$$

R_s = Resistance of sweep

C_{Ds} = Resistance coefficient of sweep

ρ = Density of seawater (1.026 g/cm³)

d_s = Diameter of sweep

L_s = Length of the sweep

$$R_w = C_{Dw} / 2 \times \rho \times d_w \times L_w \times v^2$$

R_w = Resistance of warp,

C_{Dw} = Resistance coefficient of warp

ρ = Density of seawater (1.026 g/cm³)

d_w = Diameter of warp

L_w = Length of the warp

$$R_D = \frac{C_{Dd}}{2} \times \rho \times v^2 \times S_d$$

R_D = Resistance of the door

C_{Dd} = Estimated drag coefficient of trawl door (hydrodynamic resistance coefficient)

S_d = Surface area of the door (m²)

Friction force

Friction force that acts in the opposite direction of the tow (between structural elements of trawl gear such as door, sweep and footrope and sea floor) were also calculated. The sliding friction depends on the weight of the equipment in water and the seabed conditions (Sala, 2013). The footrope weight is considered as the overall weight (including the additional weights) depending on the material of the footrope in each net (Sala, 2013). Polypropylene material which has a lower density than sea water tends to float, the footrope, therefore, its weight in the water was subtracted during the calculation of overall weight. The weight of footropes made of other materials is assumed as the overall weight used to sink the line as recommended by Sala (2013). The effective otter board weight is the weight in water. The difference between the doors' weight in water and air is related to the used material (Sala, 2013). The weight of the otter board in water is usually around 87% of the weight in the air when the otter board is constructed with solid steel, while it is 60% when wood is preferred (Sala, 2013). Expression of the friction force is given by the following equation (Sala, 2013):

$$F_{fr} = k \cdot N$$

Where F_{fr} is the friction force, k is the friction coefficient on the element and the contact surface and N is the reaction on the contact surface. Although there are different values for the friction coefficient according to the sediment type (Fridman, 1969; Sala, 2013), ground effect coefficients were taken as 0.61, 0.80 and 1.20, for door, footrope and sweep, respectively (Sala, 2013).

RESULTS AND DISCUSSION

The hydrodynamic resistance of 14 different trawl gears used around Turkey was determined theoretically. Net, floater, sweep, door, warp resistances and friction forces (occurred by footrope, sweeps and doors) of each gear was separately calculated according to different depths and towing speeds.

Hydrodynamic resistance of the nets

Among the investigated nets, the greatest total twine surface area belonged to the AS6 with a value of 1136.3 m² and the smallest to MS1 with 50.1 m² (Figure 1).

Hydrodynamic resistance force of the trawl nets varied from 1.7 kN (SM2) to 12 kN (MS4) (Table 4). The resistance of the nets be-

Figure 1. Total twine surface area of examined nets.

came bigger by the increasing the towing speed and the maximum value was determined to be 39.1 kN (MS4) (Figure 2).

Table 4. Calculating the resistance force of trawl nets depending on Nomura and Yamazaki (1975).

Net type	d/l	λ (m)	λ^2 (m ²)	R _n (kg)	R _n (N)
BS1	0.025238	28.4	806.56	508.899	4992.3
BS2	0.01989	29.9	894.01	444.5465	4361.0
SM1	0.13318	16	256	852.352	8361.5
SM2	0.020488	18.6	345.96	177.2007	1738.3
AS1	0.020386	29.5	870.25	443.5229	4350.9
AS2	0.019756	43.2	1866.24	921.7359	9042.2
AS3	0.019664	36.5	1332.25	654.9341	6424.9
AS4	0.05706	18.6	345.96	493.5119	4841.3
AS5	0.038943	27.2	739.84	720.2897	7066.0
AS6	0.048395	22.98	528.0804	638.9113	6267.7
MS1	0.030825	32	1024	789.12	7741.2
MS2	0.03163	31.8	1011.24	799.638	7844.4
MS3	0.03026	32.1	1030.41	779.5052	7646.9
MS4	0.1276	19.64	385.7296	1230.477	12070.9

R_n: Resistance of the net, d/l: the ratio between the diameter of net line and mesh length (mm), λ : Length of the headrope (m), v: Towing speed (ms⁻¹).

Figure 2. Resistance force of examined trawl nets according to different towing speeds.

Hydrodynamic resistance of Floaters

The resistance force of a 20 cm diameter spherical plastic floater ranged between 4.53 and 24.64 N under different towing speeds (Figure 3). The flotation resistance force for the Black Sea (BS1 and BS2) and the Sea of Marmara (SM1 and SM2) was 147.84 N for the Aegean (AS1-AS2-AS3-AS4-AS5 and AS6) and the Mediterranean Sea (MS1-MS2-MS3-MS4) was 264.4 N (Table 5).

Hydrodynamic resistance of sweeps

The resistance coefficient of the sweep was 0.04 at a constant flow angle of 10° (Düzbastılar et al.; 2003). The diameter and the length of the sweep are 0.032 m and 200 m, respectively, and

these values were taken to be standard measures for all of the examined nets. The resistance value of one sweep varied between 78.5 N and 427.5 N at different speeds (Figure 3).

Hydrodynamic resistance of trawl doors

Doors are basic elements for trawl operations, generating the horizontal opening in the net mouth through the arrangement of the corresponding warps. The resistance force of doors primarily depends on surface area and the towing speed. Hydrodynamic resistance of the trawl door varied in a wide range from 314 N to 1713 N (Figure 3). It is worth noting that a 2.3 times increase in the vessel speed resulted in a 5.5 times increase in the hydrodynamic resistance force.

Figure 3. Resistance force of a 20 cm diameter (D) spherical floater, 200 m long sweep and trawl doors according to different speeds (R_F; Resistance of floater, R_S; Resistance of sweep, R_D; Resistance of door).

Hydrodynamic resistance of warps

It is necessary that the angle between the warp and water surface should be definite to calculate warp resistance. The angle between the warp and the water surface ranged from 11° to 24° and the resistance coefficient of one of the warp is 0.1 at an angle of 20° (Düzbastılar et al., 2003). The resistance force of a 1m steel cable, therefore, ranged from 0.3 N to 1.7 N at different speeds (Figure 4). The length of the warps differed according to the depth of the trawl operation. The attitude of Turkish fishermen, in general, is to apply the length of warp between 3 and 5 times the operating depth. Therefore, resistance forces of a warp with different measures were shown in Figure 3 and varied between 766 N and 4174 N with different towing speeds.

Frictional resistance

In general, footrope, sweeps and doors are in contact with the sea bottom which creates frictional resistance. The frictional resistance of these elements was calculated separately.

Table 5. Cumulative hydrodynamic resistance forces of the floaters according to net type and towing speed.

Net type	Area	#	Towing speed (ms ⁻¹)				
			0.77	1.03	1.29	1.54	1.80
					Rf (N)		
BS1-BS2	Black Sea	6	27.18	48.3	75.42	108.6	147.84
SM1-SM2	Sea of Marmara	6	27.18	48.3	75.42	108.6	147.84
AS1-AS2-AS3-AS4-AS5-AS6	Aegean Sea	10	45.3	80.5	125.7	181.0	246.4
MS1-MS2-MS3-MS4	Mediterranean Sea	10	45.3	80.5	125.7	181.0	246.4
#; the number of floaters in each type of net, Rf: Resistance force of the floater in N

Figure 4. Resistance force of a 1 m long warp according to different speeds (A) and Resistance force (N) of one of the warps according to different speed and warp length (B).

Footrope friction

In order to determine footrope friction, the total weight of the footrope (additional weight and footrope weight together) in water was calculated. Estimated friction force caused by the footrope ranged between 835.5 N (BS2) and 1063.9 N (AS6) (Table 6).

Sweep friction

The weight of the sweep in water was calculated to be 545.4 N (55.6 kg). The friction coefficient between sweep and sand was

assumed to be 0.80 (Sala, 2013). Therefore; friction force caused by the sweep was determined as 436.3 N resulting in 872.6 N of total friction.

Doors friction

A wooden material trawl door weighed 1569.6 N (160 kg) in the air corresponding to 941.8 N (96 kg) weight in the water. Ninety-six kg weight equals 941.7 N which is also the normal force (N). The friction coefficient was assumed to be 0.61, therefore friction force between one door and the sediment was calculated as 5744.3 N. Total amount of friction force created by both doors was determined to be 11488.6 N.

Consequently, the total amount of friction created by sweeps and doors which were kept constant for all type nets was estimated to be 12361.2 N

Total resistance of the examined trawl gears

The total resistance force of 14 trawl nets was calculated for different towing speeds according to 1 m long warp lengths. The greatest total resistance for 1 m warp length belonged to N9, while the lowest value was detected for N8 (Table 7).

Warp length/depth ratio is generally preferred between 3:1 and 5:1 by Turkish skippers. If we assume a number of bottom trawl operations at depths of 150-250-400-500 meters, they correspond to a warp length of more or less 500, 1100, 1700 and 2500 m, respectively. Based on this assumption, theoretical total resistance force values varied between 15.4 and 63.1 kN (Figure 5).

In this study, we have determined the hydrodynamic effects on different trawl gears used in Turkish territorial waters based on theoretical assumptions. Each section of a trawl net has different contributions on the total resistance. Average resistance values of the examined nets with 500 m warp length showed that door frictions composed more than 41.3% of the total resistance, followed by net (39.4%), doors (6.3%), footrope friction (6.1%), sweep frictions (3.1%) and the rest belonged to sweeps, warps and floaters (totally 3.8%). It was determined that resistance caused by friction including sweeps, footrope and doors constituted more than 50% of the total resistance. Among the examined nets, the greatest resistance values were determined for MS4. While a total of 37.7 kN resistance value was determined for MS4 under a towing speed of 2.5 knots and 500 m warp

Table 6. Total weight of footrope in seawater.

Net	Additional weight (kg)		Footrope weight (kg)		Total weight in water		Friction force
	Weight in air	Weight in seawater	W in air	W in water	kg	N	N
BS1	125	108.6	11.8	-1.5	107.1	1050.2	840.2
BS2	125	108.6	16.4	-2.1	106.5	1044.3	835.5
SM1	125	108.6	7.8	-1.0	107.6	1055.1	844.1
SM2	125	108.6	6.6	-0.8	107.8	1057.1	845.7
AS1	150	130.3	7.0	-0.9	129.4	1269.1	1015.3
AS2	150	130.3	11.7	-1.5	128.8	1263.2	1010.6
AS3	150	130.3	10.1	-1.3	129.0	1265.2	1012.2
AS4	150	130.3	16.4	1.7	132.0	1294.6	1035.7
AS5	150	130.3	15.6	5.0	135.3	1327.0	1061.6
AS6	150	130.3	17.2	5.3	135.6	1329.9	1063.9
MS1	133	115.5	16.3	-2.1	113.4	1112.5	890.0
MS2	133	115.5	17.3	-2.2	113.3	1111.5	889.2
MS3	133	115.5	25.0	2.5	118.0	1157.6	926.1
MS4	133	115.5	21.5	2.2	117.7	1154.7	923.8

Additional weight indicates the amount of iron ($=7.8 \text{ gcm}^{-3}$) chains equipped to the footrope, - sign indicates a buoyant or floating force.

Table 7. Total resistance force of examined trawl gears based on 1m long warp length.

	Net		Door	Sweep	Warp	Resistance of floaters			Friction				
	V	R_N	$2R_D$	$2R_S$	$2R_W$	R_F	n	R_{FT}	F_{FF}	F_S	F_D	F_T	R_T
BS1	0.77	2972.8	629.3	157	0.61	4.53		27.2	840.2	872.6	11488.6	13201.4	16988.3
	1.03	5284.9	1118.8	279.1	1.09	8.05		48.3	840.2	872.6	11488.6	13201.4	19933.6
	1.29	8257.7	1748.1	436.2	1.7	12.57	6	75.4	840.2	872.6	11488.6	13201.4	23720.5
	1.54	11891	2517.2	628.1	2.45	18.1		108.6	840.2	872.6	11488.6	13201.4	28348.8
	1.8	16185	3426.2	854.9	3.34	24.64		147.8	840.2	872.6	11488.6	13201.4	33818.7
BS2	0.77	2596.8	629.3	157	0.61	4.53		27.2	835.5	872.6	11488.6	13196.7	16607.6
	1.03	4616.6	1118.8	279.1	1.09	8.05		48.3	835.5	872.6	11488.6	13196.7	19260.6
	1.29	7213.5	1748.1	436.2	1.7	12.57	6	75.4	835.5	872.6	11488.6	13196.7	22671.6
	1.54	10387.4	2517.2	628.1	2.45	18.1		108.6	835.5	872.6	11488.6	13196.7	26840.5
	1.8	14138.4	3426.2	854.9	3.34	24.64		147.8	835.5	872.6	11488.6	13196.7	31767.4
SM1	0.77	4979.1	629.3	157	0.61	4.53		27.2	844.1	872.6	11488.6	13205.3	18998.5
	1.03	8851.7	1118.8	279.1	1.09	8.05		48.3	844.1	872.6	11488.6	13205.3	23504.3
	1.29	13830.7	1748.1	436.2	1.7	12.57	6	75.4	844.1	872.6	11488.6	13205.3	29297.4
	1.54	19916.2	2517.2	628.1	2.45	18.1		108.6	844.1	872.6	11488.6	13205.3	36377.9
	1.8	27108.2	3426.2	854.9	3.34	24.64		147.8	844.1	872.6	11488.6	13205.3	44745.8
SM2	0.77	1035.1	629.3	157	0.61	4.53		27.2	845.7	872.6	11488.6	13206.9	15056.1
	1.03	1840.2	1118.8	279.1	1.09	8.05		48.3	845.7	872.6	11488.6	13206.9	16494.4
	1.29	2875.4	1748.1	436.2	1.7	12.57	6	75.4	845.7	872.6	11488.6	13206.9	18343.7
	1.54	4140.5	2517.2	628.1	2.45	18.1		108.6	845.7	872.6	11488.6	13206.9	20603.8
	1.8	5635.7	3426.2	854.9	3.34	24.64		147.8	845.7	872.6	11488.6	13206.9	23274.9

Table 7. Continue.

	Net		Door	Sweep	Warp	Resistance of floaters			Friction				
	V	R_N	$2R_D$	$2R_S$	$2R_W$	R_F	n	R_{FT}	F_{FF}	F_S	F_D	F_T	R_T
AS1	0.77	2590.9	629.3	157	0.61	4.53		45.3	1015.3	872.6	11488.6	13376.5	16799.6
	1.03	4606	1118.8	279.1	1.09	8.05		80.5	1015.3	872.6	11488.6	13376.5	19462.0
	1.29	7196.8	1748.1	436.2	1.7	12.57	10	125.7	1015.3	872.6	11488.6	13376.5	22885.0
	1.54	10363.5	2517.2	628.1	2.45	18.1		181.0	1015.3	872.6	11488.6	13376.5	27068.8
	1.8	14105.8	3426.2	854.9	3.34	24.64		246.4	1015.3	872.6	11488.6	13376.5	32013.1
AS2	0.77	5384.4	629.3	157	0.61	4.53		45.3	1010.6	872.6	11488.6	13371.8	19588.4
	1.03	9572.2	1118.8	279.1	1.09	8.05		80.5	1010.6	872.6	11488.6	13371.8	24423.5
	1.29	14956.6	1748.1	436.2	1.7	12.57	10	125.7	1010.6	872.6	11488.6	13371.8	30640.1
	1.54	21537.5	2517.2	628.1	2.45	18.1		181.0	1010.6	872.6	11488.6	13371.8	38238.1
	1.8	29314.9	3426.2	854.9	3.34	24.64		246.4	1010.6	872.6	11488.6	13371.8	47217.5
AS3	0.77	3825.8	629.3	157	0.61	4.53		45.3	1012.2	872.6	11488.6	13373.4	18031.4
	1.03	6801.5	1118.8	279.1	1.09	8.05		80.5	1012.2	872.6	11488.6	13373.4	21654.4
	1.29	10627.3	1748.1	436.2	1.7	12.57	10	125.7	1012.2	872.6	11488.6	13373.4	26312.4
	1.54	15303.3	2517.2	628.1	2.45	18.1		181.0	1012.2	872.6	11488.6	13373.4	32005.5
	1.8	20829.5	3426.2	854.9	3.34	24.64		246.4	1012.2	872.6	11488.6	13373.4	38733.7
AS4	0.77	2882.9	629.3	157	0.61	4.53		45.3	1035.7	872.6	11488.6	13396.9	17112.0
	1.03	5125.1	1118.8	279.1	1.09	8.05		80.5	1035.7	872.6	11488.6	13396.9	20001.5
	1.29	8008	1748.1	436.2	1.7	12.57	10	125.7	1035.7	872.6	11488.6	13396.9	23716.6
	1.54	11531.5	2517.2	628.1	2.45	18.1		181.0	1035.7	872.6	11488.6	13396.9	28257.2
	1.8	15695.7	3426.2	854.9	3.34	24.64		246.4	1035.7	872.6	11488.6	13396.9	33623.4
AS5	0.77	4207.6	629.3	157	0.61	4.53		45.3	1061.6	872.6	11488.6	13422.8	18462.6
	1.03	7480.2	1118.8	279.1	1.09	8.05		80.5	1061.6	872.6	11488.6	13422.8	22382.5
	1.29	11687.8	1748.1	436.2	1.7	12.57	10	125.7	1061.6	872.6	11488.6	13422.8	27422.3
	1.54	16830.4	2517.2	628.1	2.45	18.1		181.0	1061.6	872.6	11488.6	13422.8	33582.0
	1.8	22908.1	3426.2	854.9	3.34	24.64		246.4	1061.6	872.6	11488.6	13422.8	40861.7
AS6	0.77	3732.2	629.3	157	0.61	4.53		45.3	1063.9	872.6	11488.6	13425.1	17989.5
	1.03	6635.1	1118.8	279.1	1.09	8.05		80.5	1063.9	872.6	11488.6	13425.1	21539.7
	1.29	10367.3	1748.1	436.2	1.7	12.57	10	125.7	1063.9	872.6	11488.6	13425.1	26104.1
	1.54	14928.9	2517.2	628.1	2.45	18.1		181.0	1063.9	872.6	11488.6	13425.1	31682.8
	1.8	20320	3426.2	854.9	3.34	24.64		246.4	1063.9	872.6	11488.6	13425.1	38275.9
MS1	0.77	4609.7	629.3	157	0.61	4.53		45.3	890	872.6	11488.6	13251.2	18693.1
	1.03	8195	1118.8	279.1	1.09	8.05		80.5	890	872.6	11488.6	13251.2	22925.7
	1.29	12804.7	1748.1	436.2	1.7	12.57	10	125.7	890	872.6	11488.6	13251.2	28367.6
	1.54	18438.8	2517.2	628.1	2.45	18.1		181.0	890	872.6	11488.6	13251.2	35018.8
	1.8	25097.2	3426.2	854.9	3.34	24.64		246.4	890	872.6	11488.6	13251.2	42879.2
MS2	0.77	4671.1	629.3	157	0.61	4.53		45.3	889.2	872.6	11488.6	13250.4	18753.7
	1.03	8304.2	1118.8	279.1	1.09	8.05		80.5	889.2	872.6	11488.6	13250.4	23034.1
	1.29	12975.4	1748.1	436.2	1.7	12.57	10	125.7	889.2	872.6	11488.6	13250.4	28537.5
	1.54	18684.5	2517.2	628.1	2.45	18.1		181.0	889.2	872.6	11488.6	13250.4	35263.7
	1.8	25431.7	3426.2	854.9	3.34	24.64		246.4	889.2	872.6	11488.6	13250.4	43212.9

Table 7. Continue.

	Net		Door	Sweep	Warp	Resistance of floaters			Friction				
	V	R_N	$2R_D$	$2R_S$	$2R_W$	R_F	n	R_{FT}	F_{FF}	F_S	F_D	F_T	R_T
MS3	0.77	4553.5	629.3	157	0.61	4.53		45.3	926.1	872.6	11488.6	13287.3	18673.0
	1.03	8095.2	1118.8	279.1	1.09	8.05		80.5	926.1	872.6	11488.6	13287.3	22862.0
	1.29	12648.7	1748.1	436.2	1.7	12.57	10	125.7	926.1	872.6	11488.6	13287.3	28247.7
	1.54	18214.1	2517.2	628.1	2.45	18.1		181.0	926.1	872.6	11488.6	13287.3	34830.2
	1.8	24791.4	3426.2	854.9	3.34	24.64		246.4	926.1	872.6	11488.6	13287.3	42609.5
MS4	0.77	7187.9	629.3	157	0.61	4.53		45.3	923.8	872.6	11488.6	13285	21305.1
	1.03	12778.5	1118.8	279.1	1.09	8.05		80.5	923.8	872.6	11488.6	13285	27543.0
	1.29	19966.4	1748.1	436.2	1.7	12.57	10	125.7	923.8	872.6	11488.6	13285	35563.1
	1.54	28751.6	2517.2	628.1	2.45	18.1		181.0	923.8	872.6	11488.6	13285	45365.4
	1.8	39134.1	3426.2	854.9	3.34	24.64		246.4	923.8	872.6	11488.6	13285	56949.9

V: Towing speed (knot), R_N : resistance of net, R_D : resistance of door, R_S : resistance of sweep, R_W : resistance of warp, R_F : resistance of floater, n: number of floaters, R_{FT} : Total resistance of floaters, F_{FF} : footrope friction, F_S : sweep friction, F_D : door friction, F_T : total friction, R_T : total resistance

length, the other nets had lower values. The main reasons for this case could be due to the twine diameter (see Table 2) of the net and the additional weight of the footrope which directly affected the footrope friction. On the other hand, the second and third greatest resistance values were determined for AS2, MS2, respectively. MS4, AS2, MS2 were all traditional nets, indicating that traditional type nets composed more resistance than tailored ones in general.

Although the total twine surface area of AS6 is greater than MS1, AS2, MS2, MS3, SM1, MS4 and AS5, only the net resistance of those gears is bigger than that of AS6. This is due to the material of the filament, twine diameter, mesh size and length of the head-rope. Düzbastılar et al. (2003), revealed the resistance values of conventional and tailored demersal trawl nets with various trawling speed and operation depth based on theoretical calculations. The authors calculated the total resistance of conventional and tailored trawl gears to be 7.5 and 6.9 kN, respectively at 100 m depth with a towing speed of 1.29 ms⁻¹ (2.5 knot). Considerable differences between the two studies are attributable to the magnitude of the nets, twine diameter and more importantly the impact of friction which was omitted by Düzbastılar et al. (2003).

The reason for low resistance in N8 and high resistance in MS4 is attributable to twine diameter. Almost all sections of the MS4 were rigged by PE Ø 0,25 3*10 material which resulted in thicker twines. The bigger the twine is, the more the net resists. The use of smaller diameter twines and change in the twine materials of trawl netting are reported to be other methods in order to achieve reduced drag. This situation was confirmed by Verhulst & Jochems (1993). Researchers, conducting a series of experimental fishing operations by replacing polyamide ropes with ropes made of resistant Dyneema SK 60 in the front part of a large Dutch pelagic trawl, reported that it was possible to achieve ~10% higher towing speed for the same engine power with the new type of rope. They also noted that the mouth area of the net

increased by 25%, apart from the increased towing speed. Other methods used for achieving reduced drag are the use of smaller diameter twines and change in the twine materials of trawl netting. Verhulst & Jochems (1993) conducted a series of experimental fishing operations by replacing polyamide ropes with ropes made of resistant Dyneema SK 60 in the front part of a large Dutch pelagic trawl. The results show that it is possible to achieve ~a 10% higher towing speed for the same engine power with the new type of rope. It was reported that the door can comprise 30-35% of the total drag of the trawl gear and thus 30-35% of the fuel usage (Bankston, 1988). Nearly 50% of the total resistance (door frictions 41.3% and resistances of doors 6.3%) was obtained by doors and their interactions with the ground in our study. Therefore, doors are one of the most important elements of the trawl fishery in terms of hydrodynamic impacts.

Despite the increasing length over all (LOA) and engine power of trawlers and improved net structures, almost the same door design and structure have been used in the Turkish demersal trawl fishery for many years (Aydın & Düzbastılar, 2011). In this study, each trawl door resistance varied in a wide range from 314 N to 1713 N. There are other types of doors creating less resistance values (SEAFISH, IFREMER & DIFTA 1995). Such types should be theoretically examined and observed during trawl operations in the Turkish demersal trawl fishery to reduce the resistance, thus, the fuel consumption.

It is possible to calculate the resistance values of whole trawl gear in different sizes and properties by theoretical resistance calculations. While most of the previous studies took into account the design of the gear, the water speed, and the bottom contact (Ward & Ferro, 1993; Ferro et al., 1996; Sala, De Carlo, Buglioni, & Lucchetti, 2011; Park, 2007; Lee et al., 2005; Tsukrov et al., 2003; Priour, 2013) but there are few studies on catch effect (O'Neill, Knudsen, Wileman, & McKay, 2005.; Priour & Hermann, 2005). Detailed investigation of catch weight influence

Figure 5. Total resistance values (kN) of the examined trawl gears according to four different warp lengths ((A) 500 m, (B) 1100 m, (C) 1700 m, (D) 2500 m).

on trawl behavior based on sea trials was carried out by Daniel & Amelia (2015) and they stated that besides the catch weight, catch volume is also very important because the density of fish is not exactly the density of water, and this difference could slightly affect the volume of the catch. Therefore, biological factors must be added into the calculations in order to make factual estimations in further studies. It is also very important to measure the tension on the warp with suitable force gauges for

accurate determination of the total resistance of the trawl gear. Although Düzbastılar et al. (2003), reported total resistance of traditional and tailored bottom trawl nets, they excluded the effect of bottom contact and floater resistance from their calculations. Moreover, our study, parallel with that of Düzbastılar et al (2003), is missing the influence of catch weight on trawl behavior. At this point, as mentioned by Daniel & Amelia (2015), taking the catch mass and volume into account becomes very important in order to reflect or at least to reliably simulate the actual response of the gear.

CONCLUSION

Different types of trawl nets have been operated in the Turkish demersal trawl fishery according to the target species. Hydrodynamic resistance of the most common ones was theoretically estimated in the study. The greatest contributions to total resistance were composed of door friction, net and doors, respectively. Twine thickness and additional weights on the footrope were also determined to be major parameters directly affecting the net resistance. The present work is considered to inspire further studies on mathematical modelling of bottom trawl gears and, thus, comprehensive projects which contribute to the trawling efficiency will be performed.

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