Appendix - Reconstructing the fishing effort of Red Sea fisheries, 1950-2010[1]

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Fishing effort is any activity or device deployed to catch fish, and which can be quantified. Thus, the number of nets of a certain type deployed in a set period is a measure of effort, as is the amount of fuel used by a fishing fleet. Another measure of fishing effort is the cumulative engine power of the engine deployed in fisheries that are motorized. Fishing effort is an important requirement for fishery stock assessment; however, it is not usually readily available; indeed, its availability is usually worse than that of catch data. The Red Sea fisheries are divided into two major sectors: industrial and artisanal. The industrial fishery has generally better records than the non-industrial, i.e.,

artisanal and subsistence fisheries. The effort data for the industrial fishery (trawl and purse seine) of the Red Sea was obtained from the database of the *Sea Around Us* (Anticamara *et al.* 2011). This consisted of total effort by gear from 1950 to 2006 for whole Red Sea, but without disaggregation by the countries bordering the Red Sea. Thus only the total by gear for the whole Red Sea is presented in the result below. These data were extended from 2007 to 2010 by assuming the annual rate of change in effort to be the average annual change from 2000 to 2006 for purse seiners and from 2000 to 2005 for trawlers. (Note that the trawler data for 2006 jumped by order of magnitude from the previous years; thus, to keep our rate of change on the conservative side, the 2006 data were omitted).

The artisanal and subsistence fisheries do not have an effort recording system and thus the time series of effort for the Red Sea fisheries was derived mainly on the basis of demographic information (i.e., number of fishers), or boat counts. Table (1) lists the references from which the effort data were obtained for each country. For Yemen, the available data were total number of boats; Egypt has a database from which the effort data was reconstructed and for Eritrea, there were two different data types to perform the analysis for two periods, before and after 1991, when Eritrea became an independent country. Jordan and Israel have very small fishing operation in the Red Sea, hence their effort estimation is not included here.

Except for Egypt and Eritrea after 1991, the effort reconstruction procedure was the same. First, an exponential function was fitted to the available effort, which was then used to predict effort for years it was missing. The exponential function fitted had the form y = a * e[b]; where *a* and *b* are parameters to be estimated, and presented in Table (2) for each country.

Table 1. Sources used for the reconstruction of effort of the Red Sea fisheries.

Country	Year	Data*	Source	Year	%	Source
		Effort data			**Motorization data**	
Sudan	1955	200	Kristjonsson (1956)	1956	1.93	Kristjonsson (1956)
	1976	418	ODA (1983)	1979	22.57	Barrania (1979)
	1979	437	Barrania (1979)	1982	61.98	Chakraborty (1983)
	1981	664	ODA (1983)	2006	95.00	FA (2007)
	1982	605	Chakraborty (1983)			
	2001	743	FA (2007)			
	2006	967	FA (2007)			
Eritrea	1964	3543	Grofit (1971)	1960	1.00	Grofit (1971)
	1968	4167	Grofit (1971)	1963	2.20	Grofit (1971)
	1969	3022	Grofit (1971	1964	3.72	Grofit (1971
	1970	3000	Giudicelli (1984)	1969	42.10	Grofit (1971
	1981	875	Giudicelli (1984)	1974	75.00	Giudicelli (1984)
	1984	250	Giudicelli (1984)			
Yeman	1972	1000	Agger (1976)	1972	10.00	Agger (1976)
	1975	1066	Walczak (1977)	1975	26.45	Walczak (1977)
	1976	1071	Campleman (1977)	1978	60.66	Campleman (1977)
	1978	1597	Campleman (1977)	2006	96.00	MoFW (2010)
	1992	1771	Herrera and Lepere (2005)			
	1997	2686	Brodie *et al.*, (1999)			
	1998	3390	FAO (2002)			
	2000	1781	MoFW (2010)			
	2001	2254	MoFW (2010)			
	2002	2562	MoFW (2010)			
	2003	2737	MoFW (2010)			
	2004	4510	MoFW (2010)			
	2005	5000	MoFW (2010)			
	2006	5727	MoFW (2010)			
Saudi Arabia	1954	2500	Neve and Al-Aiidy (1973)	1955	0.20	Ferrer (1958)
	1971	3250	Neve and Al-Aiidy (1973)	1965	30.77	Neve and Al-Aiidy (1973)
	1980	3678	Barrania *et al.*, (1980)	1969	41.43	Neve and Al-Aiidy (1973)
	1984	2408	Kedidi *et al.*, (1984)	1991	97.00	Sakurai (1998)
	1991	2993	MAW (2008)			
	1992	3443	MAW (2008)			
	1993	3907	MAW (2008)			
	1994	4063	MAW (2008)			
	1995	4316	MAW (2008)			
	1996	4212	MAW (2008)			
	1997	4145	MAW (2008)			
	1998	4209	MAW (2008)			
	1999	4764	MAW (2008)			
	2000	5037	MAW (2008)			
	2001	6116	MAW (2008)			
	2002	6389	MAW (2008)			
	2003	6927	MAW (2008)			
	2004	7266	MAW (2008)			
	2005	6880	MAW (2008)			
	2006	7533	MAW (2008)			

* All effort data are number of fishers except for Yemen, which is number of boats.

Motorization of the fishing vessels affects how effort is calculated significantly, and thus the process was considered explicitly. The rate at which motorization took place in the Red Sea countries was fitted to the logistic curve equation:

$$y = \frac{1}{1 + e^{(\ln a - bx)}}$$

where *ln a* and *b* are parameters to be estimated, and whose values are presented in Table (2) for each country

Table 2. Parameters of exponential and logistic fitting of effort reconstruction.

	Exponential fitting			Logistic fitting		
	a	b	R^2	*ln a*	*b*	R^2
Sudan	1.00E-22	0.0287	0.89	281.50	0.1419	0.97
Eritrea*	5.00E+106	-0.1210	0.92	861.09	0.4369	0.98
Yemen	4.00E-32	0.0400	0.78	277.36	0.1399	0.89
Saudi Arabia	9.00E-16	0.0220	0.64	487.04	0.2467	0.88

* only until 1991.

Using the logistic curve fitting results, the total effort was divided into motorized and non-motorized. For the non-motorized effort, number of fishers were converted to horsepower (hp) assuming that the muscle power extend by a healthy man corresponds to 0.18 hp (Dalzell *et al.* 1987). For Egypt, Sudan, Eritrea and Saudi Arabia, the total effort was given in number of fishers. The total number of boats in the non-motorized category for Yemen was converted to total number of fishers by the average number of fishers per boat (n = 5).

For the motorized part of the fishery, the horsepower equivalent for each fisher in the motorized boats was first calculated for at least two years in the time series. A minimum of two points are needed to account for the change in the power of the engines installed in the boats over time. Using those points, a time series of hp/fisher was established, which was used to calculate the total hp by multiplying its values for specific years by the total number of fishers. For Yemen, since the total boats were given instead of total number of fishers, a time series of hp/boat was calculated as a multiplier of the total number of boats. Then the cumulative hp from the non-motorized and that of the motorized effort were added to get the overall total hp for each country.

With regard to Egypt, the fisheries included in the analysis are referred by the Egyptian authorities as 'semi-industrial' (or launch) and 'traditional' fisheries, which are referred here as artisanal and subsistence fisheries, respectively. For the artisanal fishery, effort, expressed as total number of trips, was available from 1980 – 2006 (GAFRD 2010) for the main landing site of Suez. First, the number of trips was converted to hp using the average hp/trip calculated from data given in Sanders *et al.*, (1984). A linear function (a = 1.34*104, b = 2.58*107), was then fitted and used to estimate the effort from 1950 to 2010. The effort from Suez was scaled up to the whole Red Sea using the Suez effort ratio in the whole Red Sea, which was calculated to be 47.7 % (Sanders *et al.* 1984). For the subsistence fishery, only one data point for 1983 was available (Chakraborty *et al.* 1983; Chakraborty 1984) and population numbers (all population data used in this report are based on UN population data available at esa.un.org/unpd/wpp/Excel-Data/population.htm) were used as a proxy to calculate effort from 1950 to 2010. Once the total effort for the non-industrial fishery of Egypt was calculated, it was further divided into gears. Handline and gillnet are the dominant gears and were allocated 63% and 27%, respectively based on information from fisheries experts in Egypt.

The effort data for Eritrea after 1991 was calculated using data available from the Ministry of Fishery (MOF 2007), which divides it by gear and boat type from 1996 – 2006. The effort data for 2005 and 2006 were unreasonably low compared to the previous years (so much that the catch per unit of effort for 2005 and 2006 were more than 40 times the previous years, although no major changes occurred during that time). Thus, we did not use the effort data for 2005 and 2006. Instead the average catch/effort from 1996 to 2004 were used to calculate the effort from 2005 to 2010. For 1992 – 1995, interpolation was used to fill the gap.

Subsequently, all efforts were re-expressed in kilowatt-hours. Thus, it was assumed that boats operate 2/3 (243 days) of the year, while for the rest of the year, they are docked for maintenance and/or the fishers are selling their catch or performing other land-based activities. Based on interviews with fishers, an average of 10 hours/day was used to calculate hp·hours from hp·days. Horsepower was converted to watts using the conversion ratio of 1 hp = 745.7 watt.

All the major gear used by artisanal and subsistence fishers are included in this analysis, but there are minor gears which are not. Thus, only 90% of the total effort calculated was used in dividing the total effort to the major gears. The remaining 10% were allocated to the minor gears labeled as 'others'. Three major gears, which reflect the ecosystem and behaviour of the fish were identified, namely, beach seine for small pelagic, gillnet for large pelagic, and handlining for coral reef-associated fishes. These are not exhaustive gears, but representative and major ones in each habitat. This is helpful for ecosystem based management. The final stage of the effort reconstruction is dividing total effort into gears. This was done using effort information from the sources presented in Table (1). For Sudan,
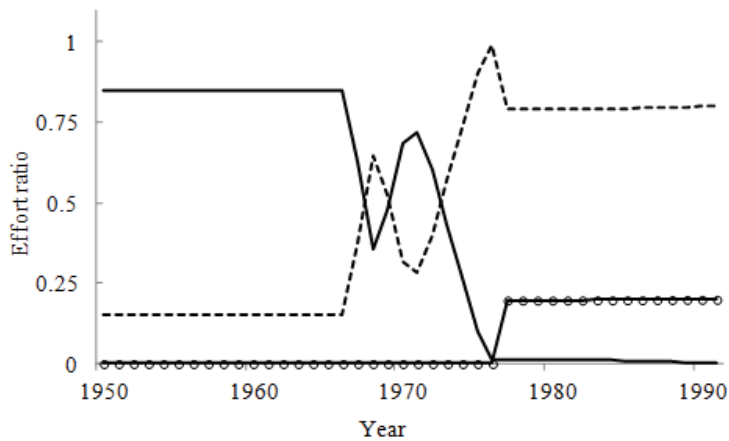
Figure 1. Ratios of beach seine (full line), handlining (broken line) and gillnet (line with circles) fisheries in the Eritrean artisanal and subsistence fisheries effort allocation from 1950 to 1991.

90% of the effort was allocated to handlining, because it is pretty much the only gear used by the artisanal and subsistence fishers, and the 10% was allocated to 'others'. For Yemen, the effort for the least important of the major fisheries, beach seine, was first dealt with, by allocating it 10% of the effort in 1950. The effort for the rest of the time was estimated using population size as a proxy and the 1950 data. This is reasonable because beach seine is carried out by people in their localities mainly for their own consumption; it is the least commercialized fishery. So, I assumed, as the population grows, more and more people are involved in the fishery. The remaining effort was divided 70% for gillnet and 30% for handline. Yemen has a dominant gillnet fishery whereas the other countries are dominated by handlining. For Saudi Arabia, the effort was divided 70% handlining and 30% gillnet. For Eritrea, the composition changed over time from beach seine being dominant in the early years to handlining being dominant in the later years (Figure 1). The total non-industrial effort for each country is given in Table (3). The total effort for the whole Red Sea by gear type was calculated by adding total efforts of the same gear from all the Red Sea countries (Table 4).

Table 3. Non-industrial fisheries effort (mega-watt hours) of the Red Sea countries, 1950-2010

Year	Yemen	Saudi Arabia	Egypt	Sudan	Eritrea
1950	683	576	6,924	66	4,181
1951	717	589	7,092	68	4,181
1952	753	602	7,265	70	4,181
1953	791	615	7,442	72	4,181
1954	833	628	7,624	74	4,181
1955	878	668	7,810	76	4,181
1956	927	689	8,000	85	4,181
1957	981	714	8,193	89	3,706
1958	1,039	741	8,390	92	3,284
1959	1,104	773	8,591	97	2,910
1960	1,175	810	8,794	101	2,579
1961	1,254	854	8,999	106	2,286
1962	1,342	906	9,207	112	2,026
1963	1,440	969	9,417	117	1,909
1964	1,549	1,044	9,628	124	1,897
1965	1,672	1,136	9,841	131	2,023
1966	1,810	1,246	10,055	140	2,325
1967	1,965	1,379	10,271	149	2,844
1968	2,140	1,537	10,486	159	3,603
1969	2,337	1,725	10,700	170	4,587
1970	2,559	1,944	10,911	183	5,724
1971	2,809	2,403	11,120	197	6,887
1972	3,090	4,110	11,326	213	7,926
1973	3,405	6,365	11,532	231	8,722
1974	3,757	9,218	11,739	251	9,220
1975	4,150	12,694	11,949	273	9,427
1976	4,586	16,786	12,164	297	9,392
1977	6,755	21,462	12,382	323	9,176
1978	9,454	26,666	12,604	585	8,837
1979	12,762	32,331	12,830	831	8,419
1980	16,754	38,387	13,061	1,130	7,958
1981	21,508	44,773	13,297	1,487	7,476
1982	27,100	51,435	13,537	1,907	6,992
1983	33,598	58,334	13,781	2,396	6,514
1984	41,070	65,444	14,031	2,957	6,051
1985	49,572	72,749	14,285	3,595	5,606
1986	59,157	80,243	14,545	4,311	5,183
1987	69,868	87,929	14,810	5,108	4,783
1988	81,744	95,814	15,075	5,987	4,406
1989	94,817	103,907	15,335	6,947	4,053
1990	109,114	112,223	15,586	7,989	3,723
1991	124,662	120,775	15,826	9,111	3,415
1992	141,486	129,578	16,058	10,312	4,841
1993	159,610	138,648	16,283	11,592	6,267
1994	179,062	148,001	16,507	12,949	7,692
1995	199,875	157,650	16,732	14,381	9,118
1996	222,082	167,613	16,960	15,889	10,544
1997	245,727	177,902	17,190	17,471	17,757
1998	270,855	188,534	17,422	19,129	19,423
1999	297,522	199,521	17,658	20,861	26,566
2000	325,786	210,879	17,897	22,669	31,543
2001	355,718	222,621	18,139	24,555	23,763
2002	387,390	234,762	18,386	26,519	27,560
2003	420,886	247,316	18,637	28,564	10,111
2004	456,294	260,296	18,892	30,693	19,669
2005	493,712	273,717	19,151	32,908	11,011
2006	533,242	287,594	19,413	35,212	12,596
2007	574,995	301,940	19,678	37,609	14,431
2008	619,091	316,772	19,947	40,102	16,985
2009	665,654	332,104	20,218	42,696	19,625
2010	714,817	347,951	20,492	45,394	17,899

Table 4. Effort (mega-watt hours) of Red Sea fisheries by gear, 1950-2010.

Year	Gillnet	Handlining	Trawl	Beach Seine	Purse seine	Others
1950	2,412	5,515	1,685	3,260	122	1,243
1951	2,482	5,639	2,010	3,261	153	1,265
1952	2,554	5,768	2,396	3,262	152	1,287
1953	2,629	5,900	2,487	3,262	153	1,310
1954	2,707	6,035	2,634	3,264	190	1,334
1955	2,796	6,191	2,753	3,265	185	1,361
1956	2,883	6,345	2,843	3,266	185	1,388
1957	2,975	6,436	2,625	2,903	201	1,368
1958	3,071	6,539	2,772	2,582	208	1,355
1959	3,173	6,656	2,677	2,298	238	1,347
1960	3,282	6,785	1,542	2,046	132	1,346
1961	3,398	6,928	1,617	1,824	137	1,350
1962	3,522	7,084	1,635	1,627	133	1,359
1963	3,656	7,271	1,874	1,539	146	1,385
1964	3,801	7,485	1,859	1,532	146	1,424
1965	3,959	7,733	2,276	1,631	376	1,480
1966	4,132	8,022	2,409	1,864	429	1,558
1967	4,322	8,936	2,402	1,689	419	1,661
1968	4,531	10,357	2,977	1,244	479	1,792
1969	4,762	10,744	2,244	2,061	291	1,952
1970	5,017	10,549	2,469	3,623	283	2,132
1971	5,353	11,175	2,525	4,546	254	2,342
1972	6,045	13,575	2,509	4,379	300	2,667
1973	6,906	16,820	2,511	3,503	310	3,025
1974	7,952	20,496	3,260	2,317	476	3,418
1975	9,193	24,494	3,195	956	415	3,849
1976	10,628	28,062	3,339	213	487	4,323
1977	14,944	29,929	3,902	215	791	5,010
1978	18,046	34,068	2,922	217	333	5,815
1979	21,641	38,594	4,367	220	782	6,717
1980	25,769	43,575	3,498	217	534	7,729
1981	30,463	49,010	5,165	215	993	8,854
1982	35,759	54,902	2,875	213	305	10,097
1983	41,692	61,258	3,462	211	213	11,462
1984	48,299	68,088	3,723	210	297	12,955
1985	55,613	75,404	3,740	209	295	14,581
1986	63,666	83,222	3,340	209	313	16,344
1987	72,485	91,557	3,320	208	341	18,250
1988	82,095	100,421	3,635	208	564	20,303
1989	92,517	109,827	3,305	209	729	22,506
1990	103,773	119,787	3,516	211	727	24,863
1991	115,878	130,309	3,712	223	723	27,379
1992	129,588	142,223	3,930	237	910	30,227
1993	143,888	155,021	4,382	251	839	33,240
1994	159,100	168,425	6,669	265	696	36,421
1995	175,251	182,452	6,345	278	724	39,776
1996	191,554	197,936	8,640	290	820	43,309
1997	212,045	216,096	8,731	301	1,110	47,605
1998	230,874	232,641	10,096	312	1,426	51,536
1999	252,358	253,234	13,446	323	2,103	56,213
2000	274,425	273,137	12,964	334	1,993	60,877
2001	292,899	287,072	14,137	346	2,494	64,480
2002	316,250	308,547	14,396	358	2,816	69,462
2003	340,333	312,259	14,079	371	2,526	72,551
2004	366,471	340,405	15,941	384	2,964	78,584
2005	396,431	350,622	16,653	396	3,032	83,050
2006	423,869	374,973	26,875	409	3,727	88,806
2007	455,669	397,698	27,612	422	4,016	94,865
2008	494,756	416,418	28,350	435	4,305	101,290
2009	530,136	441,684	29,088	448	4,594	108,030
2010	564,994	466,442	29,826	461	4,883	114,655

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