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Relationship between Temperature and Salinity Variations and the Fish Catch in the Egyptian Red Sea

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ABSTRACT

Hydrographic parameters are key players in the dynamics of marine ecosystems and can be altered by anthropogenic activities and climate change, especially in coastal areas. These conditions have an impact on production, the growth of plankton and fish species, and play an important role in the air-sea interaction processes. The hydrographic conditions of the Red Sea are unique, with a climate classified as very hot and extremely dry for its location between two broad deserts. The Red Sea and the Gulf of Suez contribution in the total marine fish catch in Egypt accounted for ≈ 40.9% in 2014. Despite the commercially important species of the basin, no study on the fishery or the hydrographical characteristics in the Egyptian Red Sea waters has been conducted. The area of the present work extended to cover the whole domain of the Red Sea, including the Gulfs of Suez and Aqaba.

The datasets of both sea surface temperature, salinity, and fish catch in the present study covered the period from 1976 to 2011 (36 years). Results revealed that the salinity alteration is the most hydrographic factor affecting the total fish catch in the Red Sea according to the performed stepwise regression analysis. When the sea surface salinity anomaly (SSSA) increases by one unit, the total fish catch in the Red Sea increases by 84.0 thousand tons per year. Remarkably, only the catch of the Kawakawa species is affected by the sea surface temperature anomaly (SSSTA) variations.

INTRODUCTION

Recently, the climate has been promptly changing, and ocean ecosystems are highly affected by this change **(Hollowed *et al*., 2011)**. Marine researchers are keen to examine the relationship between climate change and fishery. Climate change and its associated phenomena, such as global warming and ocean acidification have turned to be serious issues in the ocean ecosystems. Hydrographical conditions are described as the physical parameters of seawater. This comprises seawater temperature, salinity, seawater density, depth, currents and turbidity. Those parameters are key players in the dynamics of marine ecosystems and can be altered by both anthropogenic activities and climate change, especially in coastal areas. Moreover, those conditions influence the production and the growth of plankton and fish species, and play an important role in the air-sea interaction processes, which impact the mixing process leading sometimes to a poor oxygenation of the seawater and sometimes to anoxic situations and a sudden mortality of some species. Changes in the physical parameters of seawater can then have an impact on spawning, breeding, feeding areas and fish stocks **(Drinkwater, 2005)**. These variations with their associated impacts affect certain species, in particular maritime zones, but their impacts spread affecting different species in different ocean basins all over the world **(Kim *et al.*, 1997; Lehodey *et al.*, 2003; Drinkwater, 2005; Hollowed *et al.*, 2011; El-Geziry *et al.*, 2013; Güçlü, 2013; Ezenwaji *et al.*, 2014; Akimova *et al.*, 2016; Shin *et al.*, 2018)**.

The Red Sea (Fig. 1) is a marginal sea to the Indian Ocean, lying between Africa and Asia. It is connected to the ocean at its southern extremity through the Bab el Mandab Strait and the Gulf of Aden. To the North lies the Sinai Peninsula that divides the Red Sea water body into the Gulf of Aqaba (east), and the Gulf of Suez leading to the Suez Canal (west). The Sea is underlain by the Red Sea Rift, which is part of the Great Rift Valley. Seven countries border the Red Sea coastlines, with the Kingdom of Saudi Arabia having the longest shoreline along its eastern side and Egypt along its north western coast, ranking the second country having shoreline on the Red Sea **(Head & Edwards, 1987)**. The Red Sea extends longitudinally between 12° 30'N and 30° 00'N, with a total length of 1932 km, and with 280 km average width **(Morcos, 1970)**. The basin can be divided into three main water bodies: The Red Sea Proper, the Gulf of Suez and the Gulf of Aqaba.

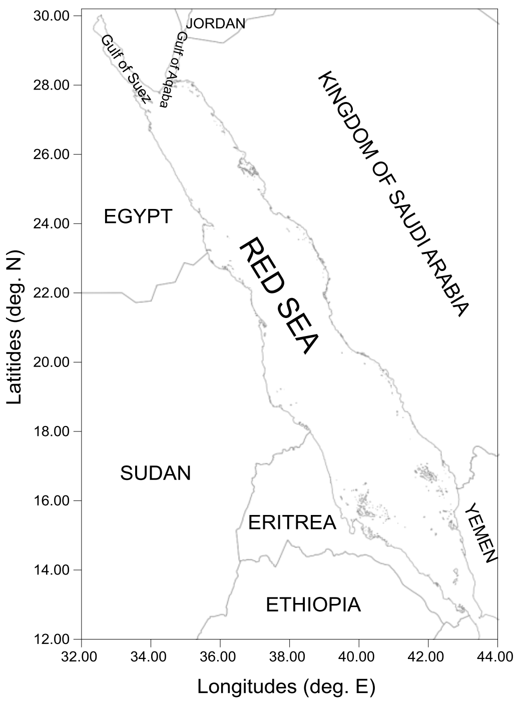

Fig. 1. A map of the Red Sea basin showing the Red Sea proper and the two Gulfs of Suez and Aqaba

The Egyptian Red Sea has a long coast of about 1080 Km, with obvious variations in topography, geology and marine ecology. This extends from Suez (Lat. 30° N) to Marsa Halayib (Lat. 22° N) at Sudano-Egyptian border. The nearshore zone is frequently bounded seaward by numerous patches of coral reefs and some lagoons, and coastal plain bounded it from the landward **(Abdel Wahab, 2010)**. Surface water salinities in the Red Sea are generally high, increasing from about 37 in the Gulf of Aden (South) to more than 41 northward, with a mean annual surface water temperature increasing from 22°C in the north to 28°C in the south, with seasonal changes more marked in the north **(Head & Edwards, 1987)**.

Hydrography of the Egyptian Red Sea

The hydrographic conditions of the Red Sea are unique. This climate is classified as very hot and extremely dry; being located between two broad deserts. Therefore, the evaporation is intensive and can reach 128 cm/year along the Egyptian Red Sea coasts **(Maiyza, 1988)**. The rainfall and precipitation are generally low and hardly exceeding 18 cm/year over the different Egyptian Red Sea sites, and the coastal vegetation is semi-desert **(Geneid, 2009)**. The average surface seawater temperature in the Egyptian Red Sea varies between 20ºC in winter and 27.49ºC in summer **(Abdel Wahab, 2010)**. The surface salinities are generally high, varying between 39.79 and 41.52 off Hurghada **(Hanna *et al*., 1988)** and between 40.3 and 40.3 in the Gulf of Aqaba **(Manasreh, 2002)**. The Red Sea is basically an oscillatory system of semidiurnal tide, where the tidal range varies between 65 and 95 cm **(Morcos, 1970)**. The currents in the Red Sea are primarily weak, much influenced by the local topography and to a less extent by tidal streams which are themselves much affected by local conditions **(Abdel Wahab, 2010)**. The velocity of the tidal currents of the mean lunar semidiurnal wave is around 2 cm/sec in the northern part of the Red Sea **(Morcos, 1970)**.

Catch composition (fish species) in Egyptian Red Sea

The catch from the marine fisheries, from both the Mediterranean and the Red Seas, represented about 8.32% and 7.37% of the total fish production in Egypt in 2013 and 2014, respectively **(Sharaan *et al*., 2017)**. According to the statistics of the General Authority for Fish Resources Development **(GAFRD, 2014)**, the Red Sea and the Gulf of Suez contribution in the total marine fish catch in Egypt was approximately 40.9%, and the remainder comes from the area along the Egyptian Mediterranean coast.

Sharaan *et al.* (2017) reported that, the Egyptian Red Sea fishery is divided into 3 main regions: (a) The Red Sea coast extending form the Suez to Halayeb, (b) The Gulf of Suez coasts, and (c) the western coast of the Gulf of Aqaba. Each fishing region includes landing sites or fishing ports. Fish catch from the area along the Red Sea coast is higher than its counterparts in the Gulf of Suez and the Gulf of Aqaba. The Red Sea coast, the Gulf of Suez and the Gulf of Aqaba contributed with about 55.7%, 43.8% and 0.5%, respectively of the average total fish catch from the Red Sea during the period from1994-2017, as shown in Table (1). The fish landing sites on the Red Sea coast are Branies, Hurghada, Ataka (outside the Gulf of Suez), Safaga, Qusseir, Abu Ramad & Shlatien. Every landing site contributes with about 22.6%, 13.6%, 10.9%, 5.4% and 3.2%, respectively, of the average total fish catch from the whole Red Sea Basin during the period from1994-2017, and with about 40.6%, 24.5%, 19.5%, 9.6% and 5.8%, respectively, of the average total fish catch along the Egyptian Red Sea coast.The landing sites in the Gulf of Suez are represented by Ataka (inside the Gulf), Tour, Salkhana and Ras Ghareb. Each landing site contributes with about 32.5%, 6.6%, 4.2% and 0.5%, respectively, of the average total fish catch from the Red Sea, and with about 74.0%, 15.1%, 9.6% and 1.3%, respectively, of the average total fish catch in the Gulf of Suez during the period from1994-2017. For the Gulf of Aqaba, fish catch contributes with about 0.5% of the average total fish catch from the Red Sea during the same period as shown in Table (3).

The evaluation of the overall fish catch composition in the Egyptian Red Sea fisheries during the period from 1994-2017 is shown in Table (2). Over the period from1994- 2017, bony fish of different types contributed with the largest ratio of fish catch (~ 81.16%) of the average fish catch from the Red Sea fisheries, as shown in Table (3). This is followed by crustaceans (Shrimps & Crabs) recording about 3.83%, and the catch of squid and octopus, with estimates of about 1.52%. Cartilaginous fish, sea cucumber and lobster contributed with about 0.35%, 0.23% and 0.02%, respectively, to the average fish catch from the Red Sea fisheries over the same period that extended from 1994-2017. These low percentages might justify the low biodiversity of the Red Sea fisheries. It is worth mentioning that, no study on the fishery or hydrographical characteristics in the Egyptian Red Sea waters was conducted before, although the basin is notably known for its commercially important species. Hence, this study aimed to investigate the fish catch in the Egyptian Red Sea waters and identify the relationship between this catch and the hydrographical parameters; namely, seawater temperature and salinity.

Table 1. Fish catch (Tons) evolution in the Egyptian Red Sea according to its fishing sea port during the period **(**1994-2017,**GAFRD, 2019)**

Land Sites / Year	Suez Gulf					Red Sea coast						Aqba Gulf	Red Sea total fish catch
	Ataka (inside Suez Gulf)	**Salkhana**	**Ras Ghareb**	**Tour**	**The Total**	**Ataka** (outside Suez Gulf)	**Ghrgada**	**Branies**	**Safaga & Quseir**	**Abu Ramad & Shlatien**	**The Total**		
1994	20770	0	0	3828	**24598**	16337	2673	0	0	0	**19010**	**339**	**43947**
1995	23788	0	0	542	**24330**	17806	3985	0	278	488	**22557**	**369**	**47256**
1996	26421	0	0	430	**26851**	14529	5865	0	322	548	**21264**	**319**	**48434**
1997	29330	0	0	876	**30206**	19291	4783	2211	93	375	**26753**	**458**	**57417**
1998	27392	0	0	1063	**28455**	15730	6357	5527	105	413	**28132**	**476**	**57063**
1999	27800	5000	0	1200	**34000**	13800	9800	22500	800	900	**47800**	**600**	**82400**
2000	29780	9424	30	1768	**41002**	13285	12021	6225	2825	295	**34651**	**319**	**75972**
2001	19763	7450	43	4953	**32209**	7613	16249	12669	2850	1579	**40960**	**380**	**73549**
2002	25364	7365	287	6812	**39828**	2238	11484	14383	2935	1663	**32703**	**358**	**72889**
2003	23415	9605	350	7141	**40511**	1697	8260	15045	3089	1539	**29630**	**267**	**70408**
2004	20550	6268	202	5582	**32602**	2300	7602	16283	3180	1665	**31030**	**282**	**63914**
2005	14154	1676	146	3201	**19177**	2494	7842	15662	3675	1619	**31292**	**263**	**50732**
2006	12455	676	70	3517	**16718**	2197	7438	14706	3907	1675	**29923**	**299**	**46940**
2007	15135	755	122	4108	**20120**	1682	7559	10970	4243	2111	**26565**	**301**	**46986**
2008	15052	530	98	3890	**19570**	2326	7286	10985	4534	2247	**27378**	**413**	**47361**
2009	14725	548	116	3993	**19382**	2479	6908	13868	3830	2276	**29361**	**288**	**49031**
2010	12443	414	866	4637	**18360**	1170	6246	12198	3801	2164	**25579**	**35**	**43974**
2011	10734	532	681	2989	**14936**	941	6384	15771	3805	2634	**29535**	**33**	**44504**
2012	8057	598	662	4282	**13599**	1243	6200	17374	3800	2611	**31228**	**39**	**44866**
2013	7950	470	676	4551	**13647**	284	6186	16627	3812	2858	**29767**	**220**	**43634**
2014	9781	439	662	4511	**15393**	222	6356	15847	4150	3040	**29615**	**45**	**45053**
2015	8394	741	694	3492	**13321**	350	6395	18174	4085	2962	**31966**	**44**	**45331**
2016	9414	743	697	4801	**15655**	454	6392	19296	4512	3332	**33986**	**49**	**49690**
2017	9969	1378	790	4142	**16279**	976	7470	18274	5249	2533	**34502**	**57**	**50838**
Avg.	17609.8	2275.5	299.7	3596.2	**23781.2**	5893.5	7405.9	12274.8	2911.7	1730.3	**30216.2**	**260.5**	**54257.9**
% from Red Sea total fish catch	**32.5**	**4.2**	**0.5**	**6.6**	**43.8**	**10.9**	**13.6**	**22.6**	**5.4**	**3.2**	**55.7**	**0.5**	**100.0**

Table 2. Evaluation of fish catch (Tons) companion in the Egyptian Red Sea fisheries during **(**1994-2017, **GAFRD, 2019)**

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Anchovy	0	0	0	0	0	0	0	0	0	4205	527	2375	3358	3667	5336	4230	3775	1719	338	3058	3408	3110	3152	3339
Arabian pinfish	6	101	2	35	36	19	10	18	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blackspot snapper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Catfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89	79	35	4	0	0	4	0	0	6
Chub mackerel	3041	1952	2042	2392	810	378	3561	2747	1614	2741	1083	553	645	1047	647	382	119	44	840	78	19	19	51	306
Common silver-biddy	0	0	0	0	0	0	0	0	0	0	0	0	0	516	735	57	50	19	9	3	23	9	8	24
Corb	0	0	0	0	0	0	0	0	0	0	0	0	0	161	6	147	115	15	25	38	91	60	282	219
Emperors	187	265	310	396	403	761	1147	2696	3513	3164	2847	1991	2589	2551	2291	2038	2831	2246	2134	2938	1892	2347	2001	1431
Ereolate grouper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95	107	98	100	102	101
File fishes	0	0	0	0	0	0	0	0	285	72	153	333	227	0	43	105	82	10	27	4	19	25	6	12
Flathead fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	158	157	167	154	113	137	90	38	22	46
Giant squid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	66	31	0	1
Goat fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	214	154	79	70	82
Greasy grouper	0	0	0	0	0	0	0	0	0	0	0	0	0	397	109	152	153	244	79	66	51	90	85	50
Great Baracuda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	36	0	23	0	0	0	0	0	4
Great barracuda	0	0	0	0	0	0	0	0	0	0	0	0	0	447	131	28	133	87	59	77	159	229	68	170
Grey Mullets	46	31	67	59	352	1811	2365	3760	3326	3515	2705	1799	1244	1125	1159	599	339	343	236	186	185	122	156	311
Groupers	247	387	647	689	722	1215	3126	3576	3687	3651	4189	3094	2601	2801	2582	3230	2871	2493	2828	2643	2494	2890	3012	2370
Horse Mackerel	11843	1269	8880	8503	9933	7441	14879	16352	18204	11230	10401	7935	5938	6522	4909	7932	6151	5913	8057	7092	7826	7196	9804	9613
Indian mackerel	1242	1378	1151	1914	652	1004	430	1442	2782	2269	1899	1467	1139	878	1080	1383	1492	2181	2143	1867	1828	2124	2927	2286
Jobfish	0	0	0	0	0	0	0	0	0	0	0	0	0	648	133	106	51	94	81	54	60	19	19	339
Kawakawa	43	138	318	755	841	326	344	209	313	537	356	135	375	638	160	167	272	182	315	219	213	295	323	402
Largeheadhairtail	0	0	0	0	0	12	2	0	0	0	0	41	2	0	4	3	0	0	3	11	0	0	0	0
Lizerfish	4845	4696	4151	5117	7994	7213	10543	7913	5736	5700	4892	2188	4162	3151	4116	4381	3915	3884	3877	3605	3901	3679	4504	4085
Needle fish	0	0	48	32	17	28	11	16	133	121	141	662	435	375	141	208	284	385	335	309	405	332	112	227
Orangespotted trevally	0	0	0	0	0	0	0	0	0	1049	1014	1288	2251	2269	1332	1402	1775	2049	1522	1674	1583	2302	2041	1691
Parrot fish	0	0	227	227	283	918	12	3009	3762	2040	1334	1481	2038	1947	1844	1370	1090	1874	1723	1419	1150	1221	1661	1531
Peacock hind grouper	0	0	0	0	0	0	0	0	0	0	0	0	0	785	1283	859	989	894	1204	1439	931	919	660	551
Red mullet	777	1077	716	744	439	876	914	2590	1684	1947	1836	713	990	988	1237	925	806	855	1267	925	1321	777	1072	1478
Red Sea seabream	0	0	0	0	0	0	0	0	0	33	0	10	0	0	2	0	4	0	0	29	0	21	10	20
Roabbitfish	35	178	128	129	175	199	42	1402	665	335	391	593	243	860	1298	478	710	955	779	783	466	536	773	664
Round herring	3195	3862	2358	2126	1162	2134	4537	2350	2282	4459	3872	855	709	2110	1325	728	793	32	343	58	38	25	17	535
Saddlekspot grouper	0	0	0	0	0	0	0	0	0	0	0	0	0	948	1233	1278	1976	1514	994	1346	1153	776	360	636
Sardine	2973	2822	6833	5639	4973	5384	5705	4343	5431	4779	3704	2887	2367	2193	3281	7295	4701	4840	5328	4146	4587	5091	6888	7921
Scade	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98	46	9	3	10	18	13
Seabream	39	178	70	49	120	182	194	1195	545	462	1554	584	629	821	210	385	323	227	451	405	312	614	380	313
Sheidhead catfish	0	0	0	0	0	0	0	0	0	103	107	98	17	79	0	0	0	0	19	8	17	1	0	11
Snapper	0	0	4044	5165	8784	4266	5236	3050	1869	542	592	1000	1008	759	1067	87	276	243	155	93	130	367	642	269
Soldier fishes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	44	107	172	125	161	163	199	141	105
Sole	0	0	0	0	0	0	0	0	0	0	0	0	48	0	22	21	0	10	52	0	0	0	0	2
Sowrd fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0
Spanish Mackerel	0	0	0	0	0	0	0	0	418	449	4931	721	294	405	181	174	349	225	174	161	233	362	289	170
Squaredtail Grouper	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	16	15
Squids	0	0	0	0	0	0	37	122	123	157	167	138	79	122	172	234	280	250	139	263	367	294	526	957
Squirrelfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	384	251	186	137	180	290

Striped piggy	4875	0	0	0	0	0	3594	1964	1887	1139	1060	799	559	518	1476	484	667	799	929	601	400	415	431	633
Sunbnose emperor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	154	402	389	365	678	551	441	370	568
Sweetlip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	33	55	86	20	66	71	90	55	33
Threadfin breams	0	0	0	0	0	0	2081	4974	3050	4205	4454	4027	3417	2278	3456	4135	2894	3393	3333	3239	2982	3162	2662	3289
Unicornfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	26	5	0	2	0	0	0	0	1
Variegated emperor	0	0	0	0	0	0	22	21	50	12	11	3	3	0	35	34	23	1	9	6	23	39	21	22
Yellowfin Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	15	16
Yellowstripe barracuda	9	13	3	1	0	3	1199	485	260	288	319	275	438	434	308	586	740	789	1142	1572	2093	1588	1309	1273
Yellowstripe Emperors	0	0	115	178	174	279	0	14	78	23	150	324	172	169	25	119	232	104	118	274	306	353	282	640
Others	332	5572	0	0	19	382	1121	89	2359	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total boney fish	**33735**	**23919**	**32110**	**34150**	**37889**	**34831**	**61112**	**64337**	**64064**	**59235**	**54689**	**38369**	**37977**	**42609**	**43853**	**46271**	**42032**	**39839**	**42217**	**42347**	**42052**	**42579**	**47523**	**49073**
Cartilaginous fish	**69**	**137**	**122**	**180**	**135**	**182**	**1962**	**624**	**337**	**209**	**127**	**51**	**126**	**115**	**80**	**81**	**23**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Lobster	0	0	0	0	0	0	20	81	28	14	41	27	2	45	12	25	1	4	13	3	1	3	1	0
Sea cucumber	0	0	0	0	0	0	20	139	2310	527	15	5	6	0	9	0	0	4	15	0	0	0	0	0
Small Shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	137	202	230	228	254
Shrimp	572	763	644	639	436	1170	2655	1623	1338	1761	2014	1957	1604	918	961	774	683	656	501	699	1946	1730	1146	447
Craps	0	10049	0	4	149	1177	2141	744	678	1998	833	371	331	311	201	297	267	321	304	98	71	241	295	283
Total Crustacea	**572**	**10812**	**644**	**643**	**585**	**2347**	**4796**	**2367**	**2016**	**3759**	**2847**	**2328**	**1935**	**1229**	**1162**	**1071**	**950**	**977**	**805**	**934**	**2219**	**2201**	**1669**	**984**
Cuttlefish	486	560	399	414	237	3525	1006	1365	854	2536	1751	1139	666	880	1387	613	276	298	159	165	311	154	157	177
Octopus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	32	37	36	37	41
Cuttlefish & Octopus	**486**	**560**	**399**	**414**	**237**	**3525**	**1006**	**1365**	**854**	**2536**	**1751**	**1139**	**666**	**880**	**1387**	**613**	**276**	**298**	**199**	**197**	**348**	**190**	**194**	**218**
Bivalves	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**973**	**811**	**64**	**70**	**238**	**69**	**40**	**49**	**38**	**1**	**42**	**26**	**65**	**45**	**7**
Others	**9085**	**11828**	**15159**	**22030**	**18217**	**41515**	**7056**	**4636**	**3280**	**3155**	**3633**	**8749**	**6158**	**1870**	**789**	**930**	**643**	**3344**	**1616**	**111**	**407**	**293**	**258**	**556**
The total	**43947**	**47256**	**48434**	**57417**	**57063**	**82400**	**75972**	**73549**	**72889**	**70408**	**63914**	**50732**	**46940**	**46986**	**47361**	**49031**	**43974**	**44504**	**44866**	**43634**	**45053**	**45331**	**49690**	**50838**

Table 3. Relatively importance of fish catch companion in the Egyptian Red Sea fisheries during **(**1994-2017, **GAFRD, 2019)**

Fish species	The average of fish catch (Tons)	% of the total
Boney fish	44033.8	81.16
Cartilaginous fish	190.0	0.35
Lobster	13.4	0.02
Sea cucumber	127.1	0.23
Crustaceans (Shrimps- Crabs)	2077.1	3.83
Cuttlefish & Octopus	822.4	1.52
Bivalves	105.8	0.19
Others	6888.3	12.70
The total	**54257.9**	**100.0**

MATERIALS AND METHODS

The area of the present work extends to cover the whole domain of the Egyptian Red Sea including the Gulfs of Suez and Aqaba.

The surface ocean layer is defined as the mean of the upper 20 m **(Solviev & Lukas, 2006; Maiyza *et al.*, 2010; Gülçü, 2013; Maiyza *et al.*, 2015** and **Sakalli, 2017)**. Therefore, the vertical mean sea surface temperature and surface salinity of the upper 20 m layer for the present study were derived from the available historical data files from the World Data Centre (WDC)-A (Washington DC), the WDC-B (Moscow), the Egyptian National Oceanographic Data Centre (ENODC), and the Ocean Data View (ODV) data bank. The mean annual value of each parameter was obtained from the World Ocean Atlas 2009 (WOA09). The deviation from this mean annual; the anomaly, was calculated for the two parameters to investigate their inter-annual variability over the study period. The dataset covers the period from 1976 to 2011, i.e. 36 years.

The data of the total catch in the present paper represent the catch along the Egyptian Red Sea coasts in 3 areas: the Red Sea proper, the Gulf of Suez and the Gulf of Aqaba. This was derived from the database on the fisheries' statistics during the period (1976-2011) from: 1- The Central Agency for Public Mobilization and Statistics (CAPMAS) during the period (1976-2002), and 2- The General Authority for Fish Resources Development (GAFRD) during the period (2003-2011). The catch comprised 6 specified species and others based on annual records during the period from 1976 to 2011, i.e. 36 years. The fish catch data were collected from the landing sites or fishing ports overlooking each of the fishing areas mentioned above. Fishing vessels are licensed to catch within specific fishing areas, but unfortunately the Egyptian fishing vessels have been known to roam the whole Red Sea, i.e. outside Egypt's Exclusive Economic Zone (EEZ) with or without official entree agreements with the other Red Sea countries **(Tesfamichael & Mehanna, 2016)**. There are even reports that Egyptian vessels -like most of fishing vessels worldwide- ensue to fishing outside the Red Sea, besides Egyptian waters in the Mediterranean, as far as the eastern Atlantic **(Feidi, 1976)**.

Time series analysis by ordinary least squares method was used to investigate the best fitted represented models of fish catch (Total fish catch and its species) and hydrographic anomalies. The represented models were chosen depending on the largest value of determination coefficient (R^2) and the least standard error of its estimate for the model. The significance of regression coefficients and the whole model were considered according to the values of (t-Test) and (F-Test), which indicate the statistical significance of regression parameters and the whole model, using the SPSS® program. These models represented fish catch (Total fish catch and its species) & hydrographic anomalies as dependent variables (y) and the time as independent variable (x).

Exponential regression using a Linear Model ($\ln y = a + bX$) or ($Y = e^{a+bt}$) of Red Sea total fish catch and its species (Y1:Y10) was used to estimate their annual change rate (%) by calculating the percentage of parameter coefficient of time variable (b*100) to identify the annual growth rate of fish catch during the study period. The coefficient of variation was calculated to examine the extent of stability fluctuations in fish catch and the hydrographical anomalies by dividing the standard deviation (SD) by the mean of all items. The lower value of the coefficient of variation for an item means it is more stable.

The estimated correlation coefficient was used to identify the relationship within the total fish catch & its species and the hydrographical anomalies; to identify the direction (Positive or Negative) of the relationship between this relationship. Additionally, using the stepwise regression analysis method was applied to determine the most influential hydrographic factor on the total fish catch and its species and the amount of this effect. This method was applied by considering fish catch (Total fish catch and its species) as dependent variables (Y1:Y8) and hydrographic anomalies as independent variables (Y9:Y10).

RESULTS

1. Mean annual sea surface temperature anomalies (MASSTA)

Results in Fig. (2) illustrate variations in the mean annual sea surface temperature anomalies (MASSTA) over the period from 1976-2011. The minimum MASSTA was -0.42°C in 1984, while the maximum was +0.51°C in 1981. The overall average of the MASSTA was +0.02°C. The MASSTA examined a very weak trend of increase over the study period with a rate of +0.0002°C/year; whereas, the best fit to express variations in the present MASSTA dataset was given by the following cubic equation:

$$y = 9 \times 10^{-5} x^3 - 0.5293\, x^2 + 1056.2\, x - 702593 \qquad (1)$$

According to this best-fit model, the minimum MASSTA occurrence was in 2004 and the maximum was in 1988.

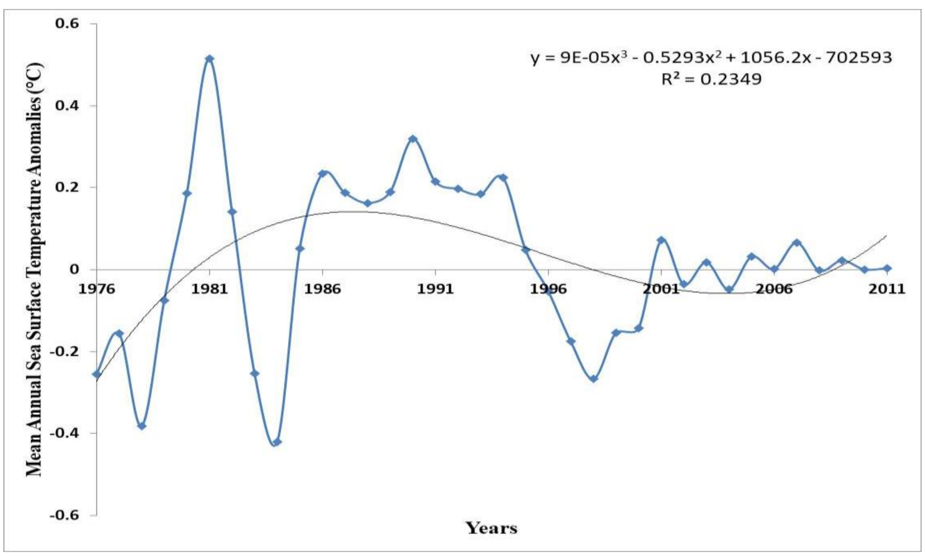

Fig. 2. Red Sea mean annual sea surface temperature anomaly (1976-2011)

2. Mean annual sea surface salinity anomalies (MASSSA)

The mean annual surface salinity anomalies (MASSSA) fluctuated between -0.34 in 2007 and +0.37 in 2000, with an overall average anomaly of +0.04 (Fig. 3). Similar to MASSTA, the MASSSA examined a very weak trend of increase of +0.001/year over the study period. The best fit model of the MASSSA dataset was expressed by the following cubic equation:

$$y = -7 \times 10^{-5} x^3 + 0.4018\, x^2 - 800.83\, x + 532010 \qquad (2)$$

This indicates a minimum MASSSA occurrence in 1983 and a maximum in 2007.

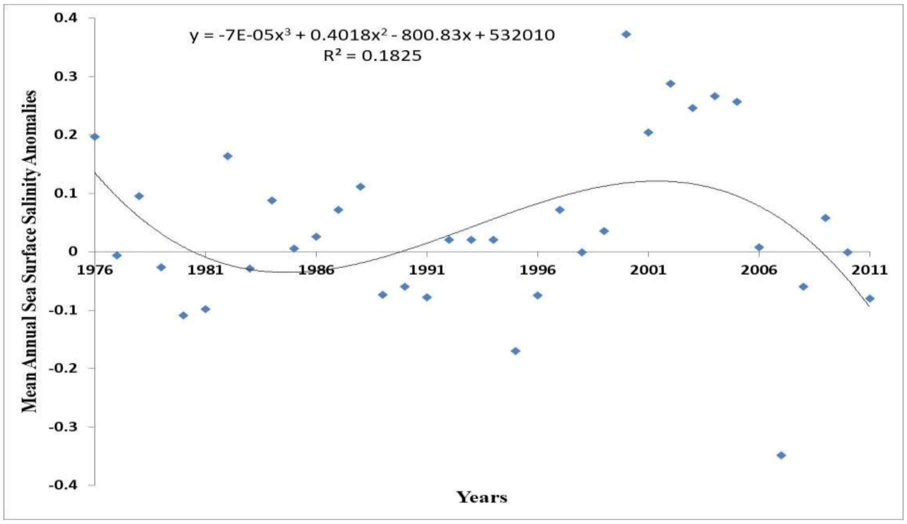

Fig. 3. Red Sea mean annual sea surface salinity anomaly (1976-2011)

3. Mean annual catch along the Egyptian Red Sea coasts

Table (4) summarizes the statistical analysis of the examined fish species in the present work. This revealed that the mean annual fish catch over the period of investigation (1976-2011) was about 39.5 thousand tons. The estimated increasing growth rate according to the exponential model is about 5.5%. This catch is characterized by a relative stability according to coefficient of variation value (54.4%). Moreover, the cubic model is the best fit-model to present the data of the red mullets, mackerel, kawakawa, groupers nei and red porgy. On the other hand, the quadratic model is the best fit-model to express variations in bushtooth lizard fish and for the set of other species.

Table 4. Common (commercial) names and the total catch of the investigated spices in the Egyptian Red Sea (1976-2011)

Item	Common name of some other species & hydrographic anomalies	Mean annual catch (tonnes/year)	% of total production	Type of model	Characteristics		Coefficient of variation	Annual change rate %
					Minimum in	Maximum in		
1	Red Mullets	710.4	1.8	**Cubic**	**1981**	**2003**	**82.9**	**7.7**
2	Mackerel	7086.8	18.0	**Cubic**	**1980**	**2002**	**62.4**	**3.9**
3	Kawakawa	199.9	0.5	**Cubic**	**1982**	**2003**	**105.6**	**8.4**
4	Bushtooth Lizasrdfish	3771.6	9.5	**Quadratic**	**-**	**2000**	**62.6**	**4.8**
5	Groupers nei	1295.6	3.3	**Cubic**	**1983**	**2009**	**107.2**	**10.6**
6	Red porgy	236.2	0.6	**Cubic**	**1984**	**2005**	**148.1**	**10.4**
7	**Other species**	26225.1	66.3	**Quadratic**	**-**	**2003**	**56.6**	**5.9**
8	**The total production**	**39525.6**	**100.0**	Cubic	1979	2002	54.4	5.5

Results recorded changes in the mean annual catch of each examined species with both the best fit-model and the representative equation (Fig. 4).

The different examined species in the present work are fit with a cubic model to present variations over the period of investigation, excluding two groups of Bushtooth Lizardfish and other species, which are fit with a quadratic model.

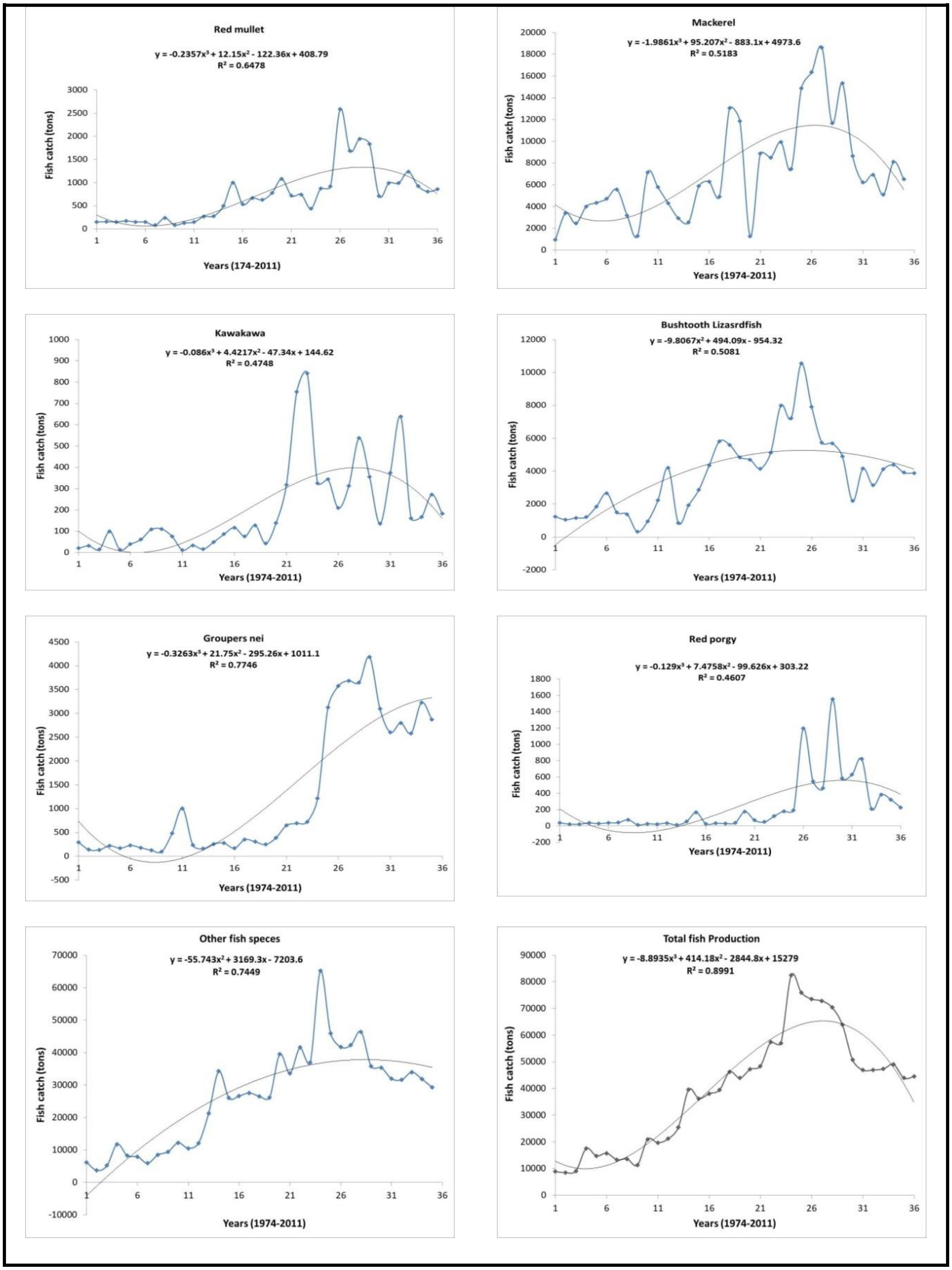

Fig. (4). Behaviour of changes in the Red Sea species and total catch over the study period (1974-2011)

DISCUSSION

The present paper is an attempt to examine the relationship between the changes in the catch of different species and the hydrographic conditions within the Egyptian Red Sea waters. It is worthnoting that, no work has addressed this point of research in this region. However, a similar investigation was carried out for the fish catch within the Egyptian Mediterranean waters **(El-Geziry *et al.*, 2013)**. **FAO (2008)** reported that change in water temperature resulting from climate change modifies the body temperature of fisheries, affecting their metabolism, growth rate, and reproduction. Also, these actions affect the general annual productivity, availability and distributions of different fish species in given locations. In the present study, however, the salinity alteration was the most hydrographic factors affecting the total fish catch in the Red Sea according to the performed stepwise regression analysis method.

When the sea surface salinity anomaly (SSSA) increased by one unit, the total fish catch in the Red Sea increases by 84.0 thousand tons per year as shown in Table (4). This is also determined for the mackerel, the bushtooth lizardfish, the groupers nei, the red mullets, the red porgy, and the other fish species' catch. An SSSA increase by one unit resulted in a catch increase by 23.02, 7.86, 6.11, 2.53, 1.48 and 42.67 tons, respectively, for the mentioned species. The SSSA upper-hand on the catch variations were previously concluded for the catch in the southeastern Mediterranean Sea **(El-Geziry *et al.*, 2013)**. One exception was recorded for the Kawakawa species, where the sea surface temperature anomaly (SSSTA) is the affecting factor on its catch variations.

CONCLUSION

To conclude, the hydrographic parameters such as temperature and salinity have considerable impact on the distribution of fish species and the catch. Results revealed that salinity has the upper hand on the catch of different species and the total catch in the Egyptian Red Sea except for the Kawakawa species, the catch of which is more influenced by the variations in temperature.

The authors highly recommend more cooperation between scientists and researchers in the fields of physical oceanography and fisheries to get robust and effective management for the world of fisheries in the Egyptian Red Sea.

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