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Fish catch patterns and estimation of maximum sustainable yield for sustainable fish catch in the fishing grounds off Gulf of Mannar, India

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Abstract
Fish catch patterns with seasonal variation of the three traditional fishing grounds off Tiruchendur coast, Gulf of Mannar was studied for the period of two years (2009-10). The main objective of the study was to estimate the maximum sustainable yield (MSY) for the sustainable harvesting. A total of 31 commercially important fishes were caught from the sampling boats, which included 9 species of pelagic, 16 species of demersal, 4 species of crustaceans and 2 species were available in mid water and benthic region. A total of 15395 kg and 15013.5 kg of fish catch were recorded at station 1 and 2 respectively. Comparatively, more fish catch about 17073.65 kg was recorded at station 3 during the study. Fish catch and CPUE showed a similar trend during the study, which indicates that fishing effort has positive impact on catch. The predicted maximum sustainable yield (MSY) for station 1 was about 665.7kg with optimum effort of 10.6 kg/h. In station 2, MSY was about 699 kg with optimum effort of 9 kg/h. At station 3, the MSY was 976 kg with an optimum effort of 11.16kg/h. The results of Schaefer model revealed that the fishery has already attained the sustainable level and also suggested that the current levels of effort are optimal.

Keywords: Gulf of Mannar, fishing grounds, pelagic fishery, Schaefer model, fish catch.

1. Introduction
Fisheries are a fundamental part of human activities in the coastal zone and this creates multiple interactions and reinforces the need for an integrated approach to coastal zone management [1]. In developing countries like India, fisheries and fishing activities are an important source of income and means of livelihood for coastal fishing folks, especially in rural areas. Almost 60.0% of the world fish catch is being fished from coastal ecosystems [2]. The discharge of untreated industrial effluent, overexploitation, alteration and loss of critical habitats that cause considerable damage to fish populations with resulting continued drop in the fish landings. India's marine fish catch had recorded at drop of five percent in 2014[3]. There is a possibility of the declining of fish catch due to various natural and manmade activities such as coastal pollution, over exploitation, uncontrolled fishing activities etc. So, sustainable fish catch is essential for sustainable utilization of fishery resources. Catches in the tropics are expected to decline a further 40% by 2050, and yet some 400 million people in Africa and Southeast Asia rely on fish caught (mainly through artisanal fishing) to provide their protein and minerals [4]. Though, there is still much ambiguity on changes of sea surface temperature (SST), ocean current pattern and hydrogen ion are expected to have direct impacts on the distribution, reproduction, dispersal, recruitment success, growth and size of fish and invertebrates associated with coastal habitats [5, 7]. The abundance and distribution of marine fish and invertebrate stocks showing large temporal fluctuations which in part are determined by changes in environmental conditions [8, 9]. The spatio-temporal variability in fish abundance and fish catch has mainly been related to oceanographic and meteorological seasonal features specifically in tropical region. The fish productivity from coastal and marine waters is primarily determined by the following factors:
i). Environmental and climate of a region [10], which determine the structure and functions of the ecosystems [11],
ii). Fishing activities [12, 13],
iii). Human induced interferences such as pollution, climate change [14].

In recent years, the increased fishing pressure on marine capture fisheries from the increased demand for seafood has caused a declining trend in productivity of fisheries globally. So sustainable fishing is an important for the maintaining the fishery resources for the future generation. Considering this, the *in-situ* fish catch patterns with seasonal variation of the traditional fishing grounds off Tiruchendur were studied for the period of two years from January 2009 to December 2010 and analyzed to evaluate and to ascertain the fishery productivity status in the coast. The main objective of the study is to estimate the maximum sustainable yield (MSY) of the fishing grounds for the sustainable harvesting, which is referred to as the Maximum Economic Yield (MEY), which is the main focus of this paper.

2. Materials and Methods

Fishing activities and pattern

In this village, 180 crafts and 760 fishermen are engaged in fishing activity. The daily fish catch data of three different chosen fishing grounds were collected by using three sample boats designated as: Boat No.1, Boat No.2 and Boat No.3 for the period of two years from January 2009 to December 2010. The list of commonly used fishing gears of Gulf of Mannar is given in Table 1. The fishing nets were employed within a radius of about 2 nautical miles in fishing grounds. The total catch per day from each sample boat was recorded and species wise quantity was recorded as soon as fish are landed. The data on landing of fish each day for the number of fishing days in each month were quantified as the total monthly catch. Data from the main gears such: drift gill nets, drag nets (shore seine), set gill nets, bottom set gill net, hook and line, long line, prawn net and stake nets employed were analyzed during the study. The catches were categorized into pelagic finfish, demersal finfish and crustaceans and identified up to species level by following the standard manuals of [15-17]. Two-way analyses of variance (ANOVA) for fish catch patterns for stations 1-3 was calculated by using statistical package SPSS (version 16.0) to understand the significance of differences of fish catch trend between temporal and spatial variations.

Table 1. Commonly used fishing gears of Gulf of Mannar

S. No	Type of fishing gear	Material	Mesh size	Species caught
1	Drift gill net (Sardine net)	Nylon Twine	20-26 mm	*S. longiceps*, *S.albella*, *Stolephorus* sp. and other small size fishes, etc.
2	Drift gill net (Mackerel and Shark)	Nylon Twine	50-56mm	*Malabar trevally*, (*Caranoides* spp.), Mackerels sp. Barracuda sp. Shark sp, seer fishes, Snapper sp., etc.
3	Bottom set gill net	Nylon Twine	20-30 mm and 80-120 mm	*Penaeus monodon, Portunes pelagicus* etc
4	Hook and line	Nylon wire with Hook (500 to 5000 hooks)	------	*Caranx* sp, *Lethrinus* sp. Snapper sp. Barracuda sp. Pomfret sp. sea bass, etc.
5	Lobster net	Nylon	80-100 mm	Lobster, *Caranx* sp. etc.

Fishing Grounds

Tiruchendur is a coastal town (Lat: 8º.29'.19.1" N and Long: 78º.7'. 26.62" E) in the Thoothukudi District of Tamil Nadu, India. It is located between Thoothukudi and Kanyakumari and situated on the bank of Gulf of Mannar, Southeast Coast of India. Gulf of Mannar, located between the southeast coast of India and west coast of Sri Lanka is a unique marine environment, and rich in biodiversity. More than 3,600 species of plants and animals inhabits Gulf of Mannar and is rightly referred as biologists' paradise. Three traditional fishing grounds were chosen for investigation is given in (Fig.1): Station 1 is located about 3.7 km from the shore at 10 meter depth (Lat: 8º.27'.28.48" N Long: 78º.8'.18.48" E). This station is well known as a lobster and other crustaceans fishing ground with rocky bottom. Station 2 is located (Lat: 8º.27'.23.32" N and Long: 78º.14'.57.06" E) about 14.1 km from the shore at 30 meter depth. The distance between Station 1 and 2 was about 10km. Cuttlefish, pomfret, sardine fishes, Indian mackerel, seer fishes and other fishes are caught in this ground designated as Station 2. Station 3 is located (Lat: 8º.30'.46.2" N and Long: 78º.16'.48.15" E) about 17.3 km from the shore at 32 meter depth and it is the important potential fishing ground for pelagic fishes such as sardine, anchovy, Indian mackerel, seer fishes and *Lates calcarifer*.

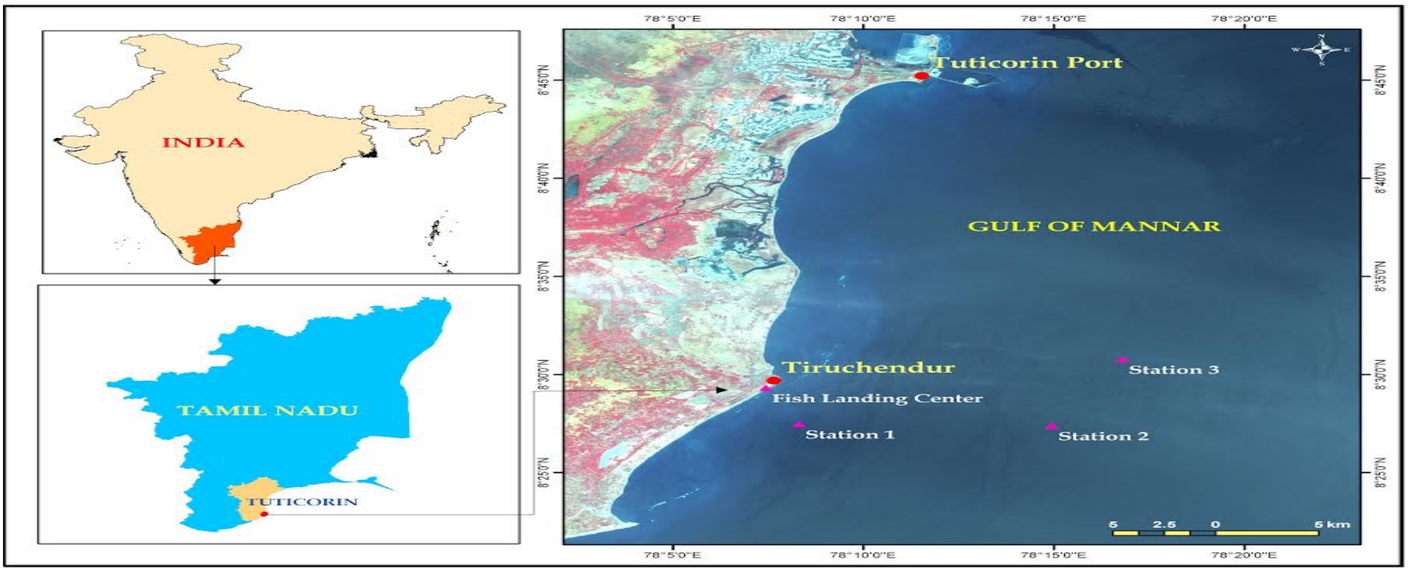

Fig 1: Map showing the study area and the location of chosen stations

Catch per unit effort (CPUE)
The nominal catch per unit effort (CPUE) was calculated by following the methods as by [18-20].

Schaefer model: Maximum Sustainable Yield (MSY)
To understand the maximum sustainable yield (MSY) in terms of total fish catch and optimum effort of the traditional fishing grounds, the Schaefer (MSY) model was evaluated by the following equations as described by [21]:

$$MSY = -a^2/4b$$
$$f(MSY) = -a/2b$$

The Schaefer model expresses the yield per unit effort (Y/f) as function of the effort (f) in the simple way as

$Y/f = a+bf$ ……. (i) (OR) $Y = AF+bf^2$ ………… (ii)

$dy/df = a+2\ b\ f$ …(iii) at 'f' corresponding to MSY (i.e. F MSY)

$dY/df = 0$……….(iv)

$0=a+ 2\ b\ f$ MSY, by substituting (IV) in (iii) ….. $fMSY= -a/2b$ ….(v)

Again substituting (v) in (ii) $MSY = a\ (-a/2b) + b\ (-a/2b)^2$
$MSY = -a^2/4b$, $f\ (MSY) = -a/2b$

Calculation of Shannon-Weiner diversity index (H'), Species richness (SR) and Species evenness
Shannon-Weiner diversity index (H'), Species richness (SR) and Species evenness were used to determine whether there were spatial and temporal differences in fish populations [22]. Shannon-Weaver [23] species diversity (H') was calculated by using the following formula:

a) Shannon – Wiener diversity Index (H') = $\sum_{i=1}^{s} Pi \log_2 Pi$

Where, S= total number of species,
Pi = ni/N for the i^{th} species,
ni = number of individuals of a species in sample,
N = total number of individuals of all species in sample.
H'= species diversity in bits of information per individual, where the value of H' is dependent upon the number of species present, their relative proportions, sample size (N), and the logarithmic base. The choice of the base of logarithm is very important. In the present study, $\log_2$ has been used as per the practice in India.

b) Species richness (SR) = (S-1) / log N

Where, S= number of species representing a particular sample,

N= natural logarithm of the total number of individuals of all the species within the sample.

c) Species evenness or equality (J') = H' / $\log_2$ S

Where, J' = species evenness,

H'= species diversity in bits of information per individual, (observed species diversity)

S = total number of species.

3. Results
Fish catch patterns showed wide inter-annual fluctuation in the fishing grounds off Tiruchendur coast, during the study period, with marginal declining trend in station 2 and 3. Two way ANOVA test of fish catch data exhibited significant temporal and spatial variations ($P \le 0.05$) during the study (Table 2). However, increasing fish catch trend was found in station 1. A total of 31 commercially important fishes were caught from the sampling boats, which included 9 species of pelagic, 16 species of demersal, 4 species of crustaceans and 2 species were available in mid water and benthic region (Table.3). *Sardinella longiceps, Escualosa thoracata, Rastrelliger kanagurta, Lethrinus ramak, Parupeneus indicus, Panilurus homorus, Epinephelus sp, Scomberomorus commerson* and *Portunus pelagicus* were the dominant species caught during the study. At station 1, fish catch varied from 477 to 954 kg/month with maximum and minimum fish catch was recorded during post monsoon season (February, 2009) and south west monsoon (September, 2009) respectively. A total of 15,395 kg of fish catch was recorded at station 1 during the study and an increasing trend of fish catch, about 325kg more fish catch was recorded during the second year. At station 2, the fish catch varied from 442 to 846 kg / month with peak and low fish catch recorded in post monsoon season (February, 2009) and summer season (May, 2010) respectively. A total of about 15,013.5 kg of fish catch was recorded at station 2 and declining trend of fish catch was noticed in the second year than the first year, during which 1114.5 kg of fish catch was decreased. At station 3, fish catch varied between 509 and 1048 kg/month. Maximum and minimum catch fish catch was recorded during post monsoon season (January 2009) and northeast monsoon (November, 2010) respectively. Comparatively, more fish catch about 17073.65 kg was recorded at station 3 during the study. The maximum fish catch was recorded during post monsoon season than other seasons in the study area as general trend. Very marginal reduction in fish catch (40.85kg) was noticed in station 3 during 2010. The recorded monthly variation of fish catch for the three stations is shown in Fig. 2

Table 2. Two way ANOVA test of the fish catch in stations 1, 2 and 3

Source of Variation	SS	Df	MS	F	Level of significance	F crit
Seasons	122279.1	3	40759.71	85.17933	$P \le 0.05$	4.757063
Stations	16681.05	2	8340.526	17.42997	$P \le 0.05$	5.143253
Error	2871.099	6	478.5165			
Total	141831.3	11				

*$P \le 0.05$; **$P \le 0.01$; ***$P \le 0.001$; NS: Not significant

Table 3. List of fish and crustaceans caught from the three fishing grounds

Pelagic fishes	
1	*Escualosa thoracata*
2	*Sardinella longiceps*
3	*Sardinella gibbosa*
4	*Rastrelliger kanagurta*
5	*Scomberomorus commerson*
6	*Chirocentrus dorab*
7	*Sepia* sp. (Cuttle fish)
8	*Euthynnus affinis*
9	Gar fish
Pelagic / Benthic fishes	
10	*Carcharhinus brevipinna*
11	*Sparus* sp.
Benthic fishes	
12	*Himantura bleekarai*
13	*Epinephelus diacanthus*
14	*Gerres filanrentosus*
15	*Caranx ignobilis*
16	*Sillago sihama*
17	*Lactarius lactarius*
18	*Lethrinus ramak*
19	Lutjanus sp.
20	*Sea bream*
21	*Epinephelus lanceolatus*
22	*Scarus ghobban*
23	*Carangoides* sp.
24	Reef cod
25	*Spirino jello*
26	*Parupeneus indicus*
27	*Cephalopholis* sp.
Crustaceans	
28	*Panulirus homarus*
29	*Penaeus indicus*
30	*Penaeus monodon*
31	*Portunus pelagicus*

Shannon Diversity

a. Shannon-Wiener diversity (H')

At station 1, fish diversity (H') varied between 2.517 to 3.112 and minimum and maximum were recorded in September (2009) and March (2010) respectively. The H' values were found minimum (2.448) in September (2010) and maximum (3.074) in February (2009) for station 2. At station 3, H' recorded with a minimum (2.121) and maximum of 3.109 in the months of July (2009) and March (2010) respectively. The Shannon diversity index for the station 1, 2 and 3 were given in Table 4.

b. Species richness

The Species richness (SR) of Simpson index of three fishing grounds was given in Table 4. At station 1, the species richness varied from 0.9048 to 0.9508 and minimum and maximum were recorded in September (2009) and March (2010) respectively. Minimum species richness (0.9051) was recorded in September (2010) and maximum (0.949) in February 2009 at station 2. Species richness varied from 0.859 to 0.9508 at station 3. Minimum and maximum values were observed in July (2009) and March (2009) respectively.

c. Pielou's evenness (J')

Pielou's evenness (J') varied between 0.7553 (June, 2009) and (0.9382) (October, 2009) at station 1. At station 2, species evenness recorded ranged from 0.7688 (January, 2010) to 0.9395 (April, 2009). At station 3, evenness ranged from 0.7401 (September, 2009) to 0.9577 (November, 2010). The Species evenness index of three fishing grounds was given in Table 4.

Table 4. Shannon diversity, species richness and species evenness at stations 1, 2 and 3

Species diversity				Species richness			Species evenness		
	St. 1	St. 2	St. 3	St. 1	St. 2	St. 3	St. 1	St. 2	St. 3
Jan'09	2.857	2.818	2.873	3.006	2.68	2.912	0.8291	0.8809	0.8422
Feb'09	2.988	3.074	3.007	3.061	3.412	3.22	0.9021	0.9015	0.8794
Mar'09	2.92	2.889	3.109	2.938	2.913	3.653	0.927	0.899	0.896
Apr'09	2.82	2.828	2.701	2.753	2.736	2.391	0.9322	0.9395	0.9313
May'09	2.886	2.974	2.666	3.241	3.171	2.654	0.8538	0.9315	0.7992
Jun'09	2.897	2.876	2.709	3.486	3.048	2.729	0.7553	0.8451	0.7899
July'09	2.571	2.55	2.121	2.191	2.198	1.584	0.8721	0.8537	0.758
Aug'09	2.781	2.942	2.853	2.925	3.319	3.278	0.8064	0.8237	0.7539
Sep'09	2.517	2.856	2.532	2.27	3.015	2.407	0.8264	0.8281	0.7401
Oct'09	2.644	2.923	2.871	2.206	3.001	2.963	0.9382	0.9297	0.8825
Nov'09	2.631	2.866	2.779	2.386	2.793	2.655	0.8684	0.9248	0.8948
Dec'09	2.816	2.85	2.45	2.707	2.767	2.126	0.9284	0.9097	0.7726
Jan'10	2.929	2.682	2.966	3.16	2.681	3.191	0.8501	0.7688	0.8441
Feb'10	2.943	2.7	2.939	3.291	2.542	3.102	0.8251	0.8266	0.8587
Mar'10	3.112	2.813	3.074	3.567	2.944	3.593	0.8987	0.8327	0.8647
Apr'10	2.826	2.593	2.878	2.858	2.243	3.118	0.8884	0.8916	0.8468
May'10	2.632	2.598	2.569	2.328	2.298	2.352	0.8689	0.8962	0.8155
Jun'10	2.752	2.593	2.428	2.667	2.22	2.186	0.8709	0.8916	0.7555
July'10	2.619	2.594	2.604	2.187	2.364	2.309	0.9146	0.8364	0.8445
Aug'10	2.9	2.78	2.941	3.071	2.611	3.298	0.8656	0.8957	0.8235
Sep'10	2.608	2.448	2.918	2.278	1.946	2.834	0.8479	0.8892	0.9249
Oct'10	2.875	2.664	2.87	2.899	2.619	2.807	0.9327	0.8439	0.9285
Nov'10	2.804	2.671	2.847	2.641	2.555	2.728	0.9176	0.8503	0.9577
Dec'10	2.651	2.598	2.564	2.683	2.419	2.458	0.7871	0.84	0.7642

Catch Per Unit Effort (CPUE)

Catch per unit effort in Station 1 varied between 6.36 kg/h and 15.36 kg/h. Maximum and minimum CPUE were recorded in the months of October (2009) and October (2010), respectively. At station 2, maximum (11.8 kg/h) and minimum (6.16 kg/h) CPUE were recorded in the months of August (2009) and April (2009), respectively. At station 3, a minimum of 7.9 kg/h during November (2010) and maximum of 16.4 kg/h were recorded during January (2010) (Fig 2).

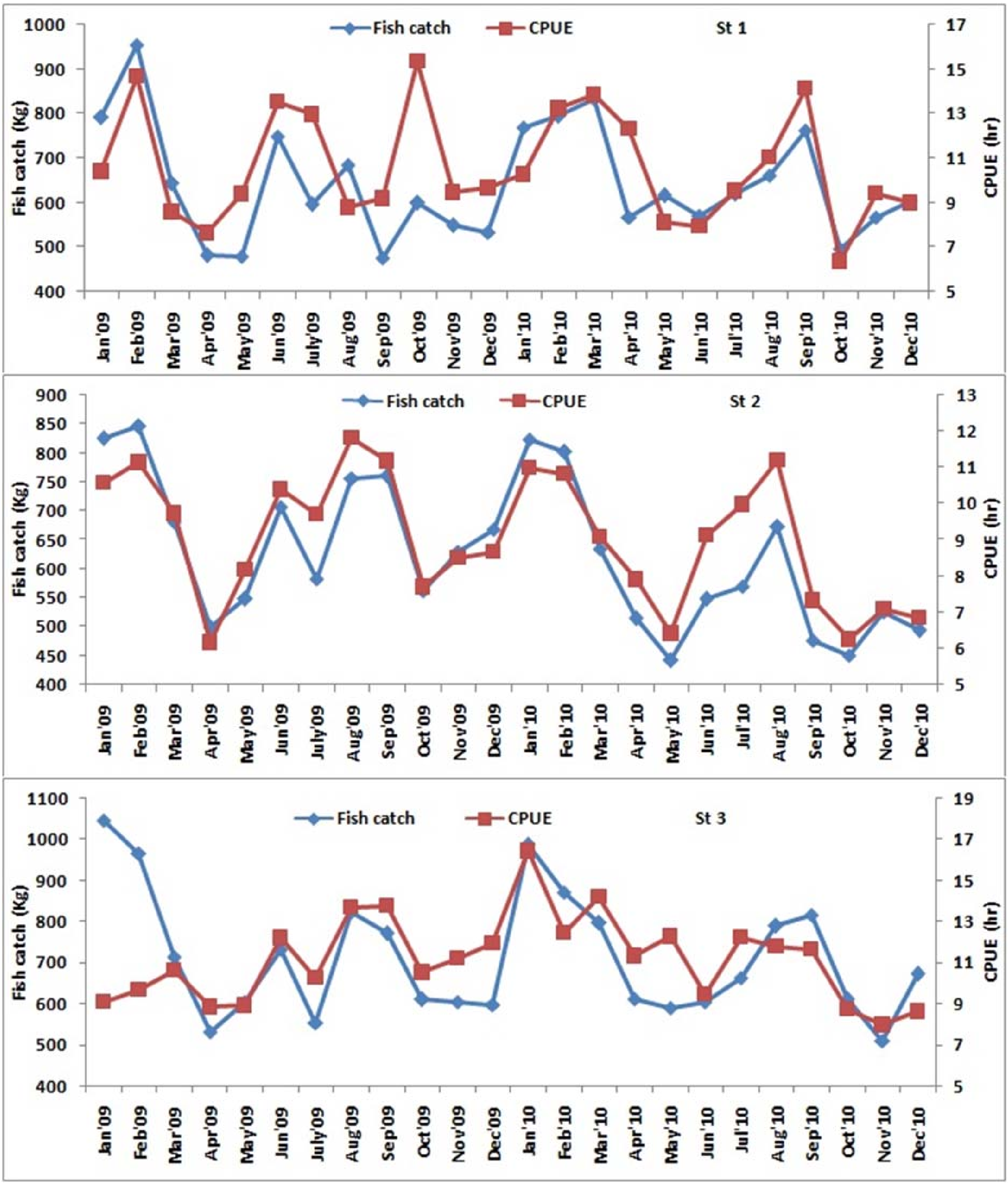

Fig.2. Fish catch and catch per unit effort (CPUE) at station 1, 2 and 3

Maximum sustainable yield (Schaefer (1954) model):

The predicted maximum sustainable yield (MSY) for station 1 was about 665.7kg while the optimum effort would be 10.6 kg/h (Fig 3). In station 2, MSY was about 699 kg and annual average catch was 625 kg with optimum effort is 9 kg/h (Fig 3). At station 3, the predicted MSY was 976 kg and annual average yield was 711kg (Fig 3) with an optimum effort value of 11.16kg/h.

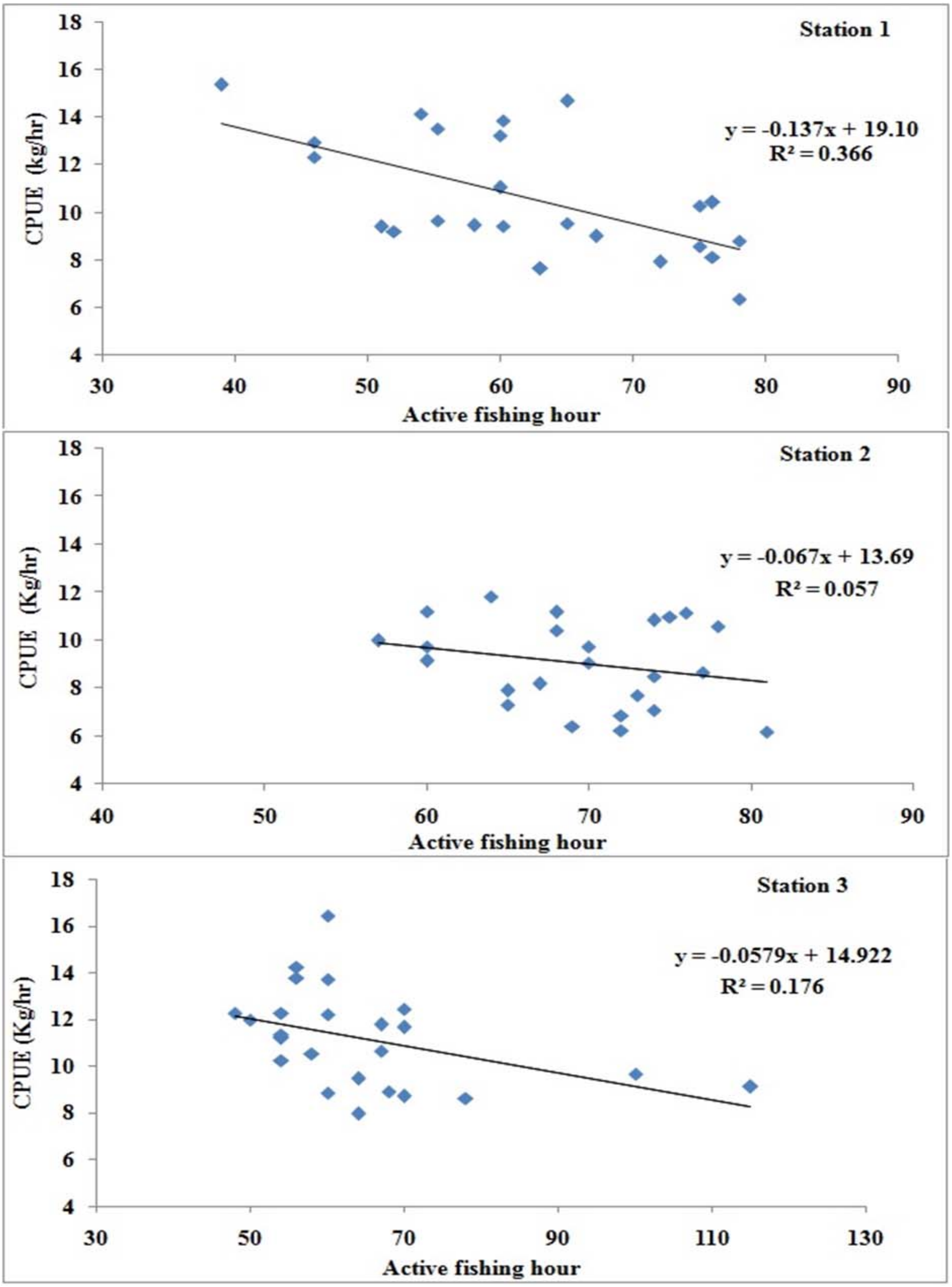

Fig 3. Maximum Sustainable Yield (MSY) model at station 1, 2 and 3

4. Discussion

The present study related the abundance of fisheries and to maintain the sustainable fish catch in the traditional fishing grounds off Tiruchendur coastal waters. The increasing demand for seafood coupled with improved technologies of capture and processing, and increasing export opportunities have led to geographical expansion of fishing in the sea. This phenomenal growth has also brought in imbalances in the exploitation level. The increased exploitation level of fishes has led to saturation level or showing declining trend in capture fisheries sector. It is expected that the loss of fishery resources and loss of predator species can have reflective and long lasting ecological effects. Apart from this, the health status of the ecosystem also affects the production of plankton which in turn directly affects the plankton feeding fishes. Understanding the mechanisms underpinning relationship of various environmental parameters and fishery productivity is essential to understand the health of the ecosystem for sustainable productivity [24]. Considering this, the *in-situ* fish catch data of the three fishing grounds and corresponding catch per unit effort (CPUE), the maximum sustainable yield were estimated for the sustainable harvest of the marine fishery resources. Thirty one commercially important species were recorded from three fishing grounds during the present study period comprising 9 species of pelagic, 16 species of demersal, 4 species of crustaceans and 2 species of pelagic/benthic ones. Among the pelagic fishes, *Sardinella longiceps*, *Escualosa thoracata*, *Scomberomorus commerson* and *Rastrelliger kanagurta* were the dominant commercial species caught during the study period. Significant changes in abundance of pelagic fishery were observed among stations.

Among the three stations, maximum fish catch was recorded at station 3 and minimum catch was recorded at station 2. Comparatively, good amount of fish was recorded in station 1 as well. At station 1, maximum fish catch was recorded during post monsoon, it was understood that, fish species diversity and richness also coincided with maximum fish catch. Fish species diversity and community structure results from the factors of species richness and evenness. Recorded high species richness in station 1 denotes that, the ecosystems ability to withstand natural disturbances that occur within the system [25]. It is to mention worthy here that, primary productivity and phytoplankton abundance were high during summer months in this region due to the favorable environmental conditions such as solar radiation, depth of euphotic zone and sea surface temperature. Thus, favorable environmental conditions persist during summer months supporting the secondary productivity also. At station 2, three peaks of fish catch were observed during first year (2009) viz., first peak in (February, 2009), thereafter fishery productivity has been drastically decreased in summer season (June, 2009) and second peak in September (2009) and third peak was noticed in December. However, a bimodal type of oscillation in fish production was recorded in the second year (2010) uniformly at all the stations. The similar trend was observed in station 3 as well. At station 3, minimum and maximum catch were recorded during monsoon season (November, 2010) and post monsoon season (January, 2009) respectively. Among the different group of fishes, demersal were the dominant group and the following order were observed pelagic > crustaceans > pelagic/benthic > other fishes during the study period. However, pelagic groups were dominant at station 1 during 2010. Generally, the catch rate trends among the fishing grounds were associated with the reproduction periods of the species [26]. Therefore, favorable hydrographical and biological conditions are vital for successful recruitment of larvae fish [27-28], which may consequently affect fishing yield [29]. From the reports of various researchers, it was evident that the environmental variability is largely responsible for the oscillations in the trend of important commercial coastal fisheries of the world, at intra as well as the inter-annual level and geographical regions [30]. In addition to that, intensity of catch per unit effort also playing an important role on fish landings. In the present study, fish catch showed significant temporal and spatial variation. The high catches recorded during post monsoon could be attributed to the growth of attaining catchable size. Fish catch and CPUE exhibited a similar trend over the months, which indicated that fishing effort had positive impact on catch. Apart from, environmental conditions, fishing pressure is one of the most significant human impacts on coastal ecosystems [2]. The MSY is also an important biological reference point used for fisheries management purpose. Since, local fishermen are artisanal fishers, are using multi gear and multi fleet to capture the fishes, it is difficult to estimate the maximum sustainable yield (MSY) of any of the individual species. Hence, an attempt was made to estimate the maximum sustainable yield (MSY) for the three fishing grounds. The predicted MSY for station 1 was about 665.7kg while the optimum effort would be 10.6 kg per hour (average). This is close to the current average yield (641 kg). At station 2, MSY was about 699 kg and annual average catch was 625 kg with optimum effort was 9 kg/hr. At station 3, the predicted MSY was 976 kg and annual average yield was 711kg with optimum effort value was 11.16kg/hr. It was come into sight that the fishery has already attained the sustainable level and also suggested that the current levels of effort are optimal. However, the fish catch effort may be increased at station 3 to get more yields.

5. Conclusion

In Tiruchendur coastal waters of Gulf of Mannar, the fish catch was observed to exhibit significant temporal and spatial variations. A total of 15,013.5 kg of fish catch was recorded at station 2 and declining trend of fish catch was noticed in the second year than the first year, during which 1114.5 kg of fish catch was decreased. Comparatively, more fish catch was noticed at station-3 and about 17073.65 kg of fish catch was recorded during the study. Very marginal reduction in fish catch (40.85kg) was noticed in station-3 during second year. From the catch per unit effort and fish catch data, it is tacit that, fish catch and CPUE follow a similar trend over the months, which indicates that fishing effort has positive impact on catch. Fishes used to spawn throughout the year in this region, however, summer months (April to May) could be considered as peak spawning season. Rich abundance of phytoplankton and zooplankton during summer months are generally utilized by various fish larvae. Thus, a favorable hydro-biological condition is vital for successful survival of fish larvae, which may consequently affect fish yield. These larvae have grown further and after six months they recruit to the fishery during post monsoon. Though summer months are being the peak spawning seasons, most of the fishes are spawning throughout year. The fishing ground 3 is the rocky areas called “paars” support variety of pelagic and demershal fishes. Higher catch and CPUE during Jan and Aug-Sep, and low during April and October-December were noticed due to favorable environmental conditions. Current fishery yields and effort are close to the maximum sustainable yield suggesting that the fishery is attained the sustainable level. From the Schaefer model, it was understood that, fishery has already attained the sustainable level in station 1 and 2. However, the CPUE may be increased at station 3 to get more yields. The results of Schaefer (1954) model provide baseline information on maximum sustainable yield for the Tiruchendur coastal waters, which could be useful for any future fishery assessment of this coast.

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