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On the reported inverse relationship of oil sardine (*Sardinella longiceps*) and mackerel (*Rastrelliger kanagurta*) landings in India

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Abstract
The oil sardine *(Sardinella longiceps)* and Indian mackerel (*Rastrelliger kanagurta)* fisheries form the main stay of the pelagic fisheries of India. Many authors reported an inverse relationship of mackerel to oil sardine fisheries, in the country. Competition for food and space has been attributed as possible cause for the observed inverse relationship. The present study was undertaken to ascertain whether there is any true relationship between the landings of these two fishes by analyzing catch data for a period of 65 years by employing Pearson product moment correlation coefficient (r). An attempt was also made to examine whether there is any true competition between the two species. The results of the study indicated no negative relationship between the landings of oil sardine and mackerel in India. Instead, there is a positive correlation, though weak, between the landings of the two species (r = 0.425). Further, there is no record to provide evidence for direct competition between the two species.

Keywords: Oil sardine, Indian mackerel, *S. longiceps, R. kanagurta*, inverse relationship

1. Introduction
The oil sardine and mackerel fisheries form the main stay of the pelagic fisheries of India. Oil sardine fisheries in India is a single species fishery contributed by *Sardinella longiceps Valenciennes*, 1847. It contributes to a third of the total marine fish production of the country in productive years [1]. The successful years of oil sardine fisheries in India bring much prosperity to the fishing community as its failure a major economic set back. The bulk of the commercial landings of mackerel in India is contributed by a single species *Rastrelliger kanagurta* (Cuvier, 1817) viz., Indian mackerel. The volume of mackerel catch in productive years is appreciable, contributing to as much as 15% or even more to the total marine fish landings [1].

Landings of both oil sardine and Indian mackerel show marked fluctuations from year to year [2]. Many authors reported an inverse relationship of mackerel to oil sardine fisheries [3, 5]. Coincidences of geographical range and season and competition for food and space have been attributed as possible causes for the observed inverse relationship.

In the absence of any targeted fisheries in the tropical regions including the seas around India for either of the two species the landings of oil sardine and mackerel are functions of stock abundance which in turn depends on the success in recruitment and growth of the fish. A negative correlation, if any found between the landings of the two species, is expected to indicate existence of competition between them for one or more common resources.

In the present study, data of oil sardine and mackerel landings in India for 65 years were examined by employing statistical methods to ascertain whether any inverse relationship exists between the landings and with the ultimate aim of understanding existence, if any, of true competition between the two species for common resources, as has been reported by many earlier authors [3, 5].

2. Materials and Methods
In India Central Marine Fisheries Research Institute (CMFRI), Kochi has been collecting species-wise marine fish landings since 1950 employing a multi stage stratified random sampling design [6]. For the purpose of the present study the annual fish catch data available in the official repository of the Institute were used [7].

The scatter diagram was obtained by depicting the annual landings of oil sardine on the X- axis and that of mackerel on the Y- axis. The relationship, if any, between the landings of oil sardine and mackerel was analyzed by Pearson product moment correlation coefficient (*r*) which is calculated as given below.

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}}$$

Where *x* and *y* denote the annual landings of oil sardine and mackerel in India in metric tons respectively and *n* denotes the number of years of observation. The correlation coefficient was calculated by employing SPC software [8]. The significance of the correlation coefficient was tested by comparing the calculated value of *r* with the critical value of *r*, for *n -2* degrees of freedom at 1% level of significance [9]. The degree of relationship between the landings of oil sardine and mackerel was measured by computing the coefficient of determination (r^2).

3. Results and Discussion

The annual landings of oil sardine and mackerel in India during the period 1950-2014 is presented in figure 1. It is clearly evident from the figure that the contribution of oil sardine to the fishery is more compared to mackerel in all years except during the period from 1950 to 1953, in the year 1956, 1963, 1986, 1989 and from 1992 to 1996. The mean landing of oil sardine for 65 years from 1950 to 2014 is 218565.20 metric tons with a standard deviation of 157663.70 metric tons. The oil sardine landing was the highest in the year 2012 and the lowest in 1956. The landings were above the average during the period from 1964 to 1968, in the years 1970, 1981, 1989, 1990, 1997 and from 1999 to 2014. In the remaining years the landings were below the average figure.

The mean annual landing of mackerel between the period from 1950 to 2014 is 111600.20 metric tons (with a standard deviation of 74316.65 metric tons) which is almost half that of oil sardine. The mackerel landing was the highest in the year 1989 and the lowest in 1956. The landings were above the average during the years 1958, 1960, 1970, 1971, from 1989 to 2000 and from 2003 to 2014. In the remaining years the landings were below the average landing figure.

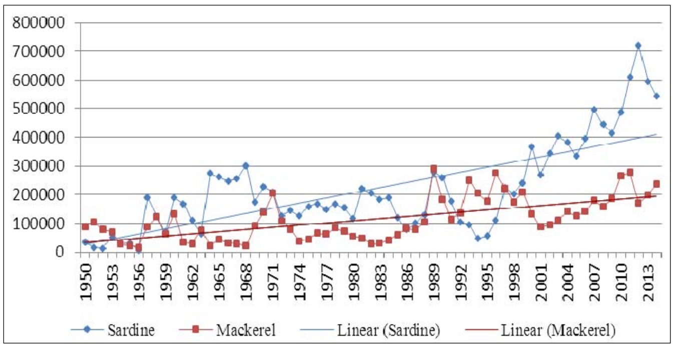

Fig 1: Annual landings of oil sardine and mackerel in India from 1950 to 2014.

The scatter diagram obtained by depicting the annual landings of oil sardine on the X- axis and that of mackerel on the Y- axis is presented in figure 2. The value of Pearson product moment correlation coefficient (*r*) is 0.4558 indicating that the relationship between the variables is positive but weak. Since the calculated value of *r* was found to be greater than the critical value of r (0.325) for *n -2* degrees of freedom the correlation was found to be statistically significant ($p \leq 0.01$). It implies that, in general, higher the oil sardine landing, higher is the landing of mackerel. However, it should be born in mind that the coefficient of correlation expresses the relationship between two series and not between the individual items of the series. The coefficient of determination (r^2) was found to be 0.2078 indicating that the correlation between the landings is weak.

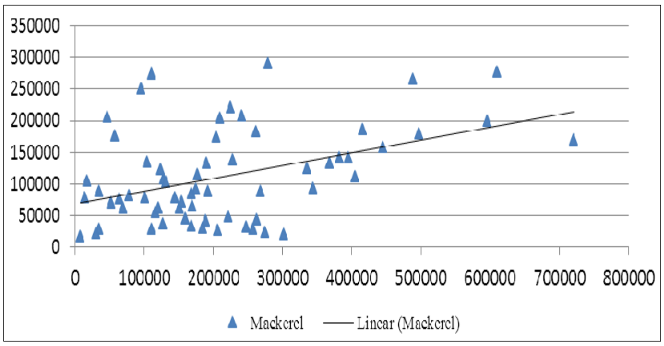

Fig 2: Scatter diagram for the annual landings of oil sardine (X- axis) and Indian mackerel (Y- axis) in India from 1950 to 2014.

The results of the present study negate the theory of inverse relationship between the landings of oil sardine and mackerel in India put forward by Hornell [3] and Nair and Chidambaram [4]. These authors found an inverse relationship between the two fisheries, the success of one inversely corresponding with that of the other.viz., a successful year of oil sardine coinciding with failure of mackerel fishery and vice versa. The relationship between the landings of the two species in the south west coast of India has recently been studied by Thara [5]), who observed a significant negative correlation with 95% confidence level during the study period. However, she used fish landing data for a relatively short period (1991-2008) in reaching the conclusion. On the other hand, the present study relied up on the catch data for 65 years and for a wider geographical area which is quite sufficient to arrive at meaningful conclusions on a fishery. The present results corroborates the observations of Bal and Rao [1], Madhupratap *et al.* [2]. Raja [10] and Longhurst and Worster [11] who pointed out lack of correlation between the landings of oil sardine and mackerel.

The question now to be answered is whether there is any real competition between the two species for the same resource. As has already been stated the landings of oil sardine and mackerel are dependent on success in recruitment and growth and the fishing effort put in. There are no targeted fisheries in the seas around India for either of the two species. In the context, landings reflect on the stock abundance. Thus studies on landings for a long period give an idea about the fluctuation in stock abundance and about existence of inter-specific competition, if any. Absence of negative correlation between the landings of the two species, as observed in the present study, discounts the theory of inter- specific competition.

It is a well established fact that when two species compete for a limited resource, one species eventually drives the populations of the other species to extinction. Competing species cannot co-exist for long. The Competitive Exclusion Principle [12] states that two species are not able to co-exist at constant population values competing for the same resource. It means that species cannot co-exist if they have the same niche. The word "niche" refers to a species' requirements for survival and reproduction. These requirements include both resources (like food) and proper habitat conditions (like temperature, pH etc.). If two species have identical niches they would attempt to live in the same area and would compete for the same resources. If this happens, the species that is better adapted would exclude its competitors from that area. Therefore, species must at least have slightly different niches in order to co-exist. To understand competition we need not only consider conditions and population attributes that lead to competitive exclusion but also situations under which similar species co-exist. Although competition between animals can be seen in a variety of situations, many species have developed elaborate strategies to avoid competition.

Oil sardine and Indian mackerel co-exist in the same coastal waters and seem, outwardly, to occupy the same niches. However a closer examination reveals that the niches are similar but different. The two species differ in at least three traits: the area of occurrence (horizontal as well as vertical distribution), feed and spawning season. Oil sardine is a pelagic, neritic fish which is distributed between 25^0 N and 7^0 N and between 57^0 E to 81^0 E [13]. It inhabits a depth range of 20- 200 m. Indian mackerel too is a pelagic and neritic species enjoying a wider horizontal distribution between 34^0 N and 24^0 S and between 30^0 E to 180^0 E [14]. It inhabits a depth range of 20- 90 m [15] viz., distributed vertically to a lesser depth- range compared to oil sardine.

Although both the species are omnivores, the adult oil sardine feeds mainly on diatoms while the mackerel is predominantly a zoo plankton feeder [16, 17]. The general view held at present by a large number of workers from different coastal zones is that the oil sardine is predominantly a phytoplankton feeder, subsisting on diatoms like *Fragilaria, Biddulphia, Coscinodiscus, Thalassiothrix* and *Pleurosigma.* Amongst them *Fragilaria oceanica* has been considered as one of the most favorite items of food. A significant correlation between its occurrence and oil sardine fishery has also been reported [18].

In the inshore waters, the food of Indian mackerel consists of phytoplankton and zoo plankton elements strained from the surrounding waters by the well developed and feathery gill rakers. The phytoplankton elements comprising the food are the diatoms represented chiefly by *Coscinodiscus, Pleurosigma, Chaetoceros, Fragilaria, Thalassionema, Nitzschia, Rizosolena, Skeletonema, Thalassiothrix, Biddulphia, and Asterionella* and the Dinophyceae by *Ceratium, Peridinium and Dinophysis*. Food items of the zooplankton items are made of varied groups of organisms and among them, the crustaceans form the major portion, with copepods in high percentage and the other crustaceans in smaller proportions constituted by the cladocerans, cirripede larvae, mysids, sergestids, some amphipods, decapod larval stages as nauplius, protozoea, zoea, mysis stages of prawns and stomatopods larvae as alima. Among the zooplanktonic items of food, other than crustaceans, there are tintinids, foramniferans, polychaete larvae, molluscan larvae, chaetognaths, appendicularians, fish eggs and fish larvae [19-23].

Thus the food of mackerel is ‘broad based’ compared to that of the oil sardine. The trophic level based on food items of oil sardine is 2.4 ± 0.22 while that of the Indian mackerel is 3.2 ± 0.38 [24] revealing the higher dependence of the former on phytoplankton compared to the latter.

Both oil sardine and Indian mackerel are surface feeders. But, when the plankton is scarce in surface waters or when they are teeming with non edible forms the latter feeds at sub surface levels on the usual items of food, the presence of which is confirmed by the examination of plankton at the respective levels. The presence of sand grains foraminiferans, fish scales etc. found among the stomach contents of mackerel is attributed to the fish feeding at times at the bottom [25]. There is increasing evidence that mackerel might move away from inshore waters and become demersal especially when there is paucity of food in the surface waters. Recent demersal trawl survey results indicate presence of mackerel in significant quantities beyond conventional zone all along west coast [26]. Sudarsan *et al.* [27] have observed that mackerel form 1 to 10% of the demersal catches along the west coast especially between 8^0 and 18^0 N. Thus the sub surface or bottom feeding habit of mackerel must be viewed as an adaptation to avoid direct competition which helps it to co-exist with the oil sardine.

The spawning season of oil sardine and mackerel is different. Indeed there is considerable disagreement of opinion among various workers on the spawning season of the two species [28-40]. However a consensus of opinion indicates that in the seas around Indian peninsula oil sardine spawns between June and October with peak during August – September. Taking west coast centers of the country together, it is seen that the mackerel spawn round the year with regional differences as the period of commencement, duration and the period of termination of spawning [1]. In general, it may be stated that the period of intensive spawning is about June- August with the commencement of spawning in about March or even earlier i.e., by about February and the termination by September or even one or two months later. Along the west coast the spawning period corresponds to the period of the south- west monsoon. On the east coast the commencement of spawning period is in October- November coinciding with the onset of the north- east monsoon and extends up to April- May, which period is just the same for the spawning of mackerel around Andaman Islands. Since the spawning season of mackerel is much ahead of that of the oil sardine, by the time the young ones of oil sardine starts intensive feeding, the mackerel would have grown and passed the stage, leaving not much room for the young ones of the two species to compete with each other. Further, juveniles of oil sardine are mainly carnivorous, feeding on planktonic crustaceans like copepods [41]. On the other hand in mackerel, the post larvae (5-6 mm) are found to be herbivorous feeding on diatoms and algae and the juveniles (25 mm) are omnivorous feeding on all available food organisms in the plankton [42]. Thus the chances of competition for food between the two species in the early life stages are avoided to a great extent.

The foregoing reveals in unambiguous terms that oil sardine and mackerel are not competitors in the true sense. There is no record to provide evidence either for direct competition between the two species or for competition in the manner of incumbent replacement, in which established groups can exclude competitors, even if those competitors possess advantageous key adaptations, until the incumbents are removed from their foothold by a major environmental disruption such as a mass extinction, at which time the key adaptations of the invading population allows them to colonize the area before the incumbents can reestablish themselves [43]. The absence of active competition, of course, does not mean that competition in the past is to be ruled out as a factor in bringing about the difference in behavior.

In a multiple fishery ecosystem there are various factors contributing to the success and failure of the fisheries. Some researchers [4, 32, 44, 45] were of the opinion that periodical migration into offshore waters, heavy natural mortality, availability of the diatom (*F. oceanica*) and over fishing were the factors responsible for the fluctuation of the oil sardine fishery. Nair [18] also indicated that optimal conditions of temperature (27-28^0 C) and salinity (34-35 ppt.) would influence the appearance of stronger shoals into the fishery. Temperature, salinity and availability of food as factors controlling oil sardine abundance have also been indicated by many authors [37, 46, 56]. The influence of rainfall on oil sardine abundance has been reported by some workers [57, 59]. Relation of oil sardine landings to wind drift was also pointed out [60]. L'onghurst and Wooster [11] have made a detailed study on the short term and long term abundance of oil sardine in relation to the oceanographic and meteorological conditions. Madhupratap *et al.* [61] have discussed the influence of various factors of coastal oceanography on oil sardine fishery. The fluctuations in oil sardine fishery is also reported to be due to fishery independent factors as its cyclic abundance pattern shows a striking similarity to the 10/11-year periodicity of sunspot activity [62]. The El Nino phenomenon that might be directly or indirectly influenced by the 11-year solar activity cycle and manifested with an abnormal increase in sea temperature and related changes in hydrographic parameters may also be considered partly responsible for fluctuations in its abundance [62]. Discussing fish population studies Banerji [63] brought out the necessity to search for fishery independent factors to answer the fluctuations in the yearly recruitment. Over abundant year class was reported to exert a great stress on the fry of one or two successive generations in mackerel causing reduction in their numbers and hence the fluctuations in the fishery [64].

The period of occurrence of mackerel shoals in the inshore waters is reflected in the duration of the fishing season. Hydrological and meteorological features seem to play important role in the migration of the shoals of mackerel, the increase in temperature and salinity seem to affect the catches adversely [65]. Mackerel seem to have higher susceptibility to variations in temperature than to salinity. It has been noticed that north easterly and easterly winds drive the mackerel shoals to inshore and close shore waters and that the movement of the shoals are usually along the water current at high tides [20].

Hornel [3] stated that periodic combination of certain unfavorable conditions in inshore waters resulting in low production of diatoms would affect the fishery of Indian mackerel. These adverse conditions, according to him, would be largely influenced by exceptional disturbances of the sea at critical junctures, by long shore current abnormal in power and direction and changes in density of inshore waters either through lack or superabundance of monsoon floods, especially at the end of southwest monsoon. Sunder raj [66] thought heavy fishing of immature fish would have adverse effect on the fishery of subsequent years. Devanesan and Chidambaram [67] were of the opinion that the intrusion of an immature generation in the fishery was a probable cause of the fluctuations in mackerel landings.

Based on the above discussion, it may be concluded with certainty that the success in recruitment and growth in oil sardine and Indian mackerel depends on prevalence of favorable climatic conditions especially the monsoon rains and subsequent availability of favored food items. Under favorable conditions for recruitment and growth, both the species take advantage which is reflected in their population growth and, in turn, in availability of the resources for fishing. Other things remaining the same, the landings of both the species are expected to increase during favorable periods. On the other hand, adverse conditions act as impediments to population growth in both the species. Thus the fluctuations in landings of the two species are caused by physical factors like temperature, salinity, rain fall, ocean currents, availability of nutrients and biological factors like availability of food items rather than inter specific competitions per se.

4. Conclusion
The present study was undertaken to ascertain whether there is any true relationship between the landings of oil sardine and mackerel landings in India by analyzing catch data for a period of 65 years by employing Pearson product moment correlation coefficient (*r*). The results of the study indicated no inverse relationship between the landings of oil sardine and mackerel in India. In fact there is a positive correlation, though weak, between the landings of the two species further, there is no record to provide evidence for direct competition between the two species.

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