Bhathal, B. and D. Pauly. 2008. 'Fishing down marine food webs' and spatial expansion of coastal fisheries in India, 1950-2000. *Fisheries Research* 91: 26-34.

'Fishing down marine food webs' and spatial expansion of coastal fisheries in India, 1950–2000

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Received 31 July 2006; received in revised form 13 August 2007; accepted 5 October 2007

Abstract

The worldwide crisis of fisheries, which are usually managed on a single species basis, has led to calls for 'ecosystem management', along with the development of various ecosystem indicators. The Marine Trophic Index (MTI) and the related Fishing-in-Balance (FiB) index are two such indicators, which can be used to draw inferences on the sustainability of fisheries, notably those targeting high-trophic level species, in an ecosystem context. These indices are used here to evaluate the status of marine fisheries in India, based on taxonomically and spatially disaggregated time series of catches covering the years 1950, when 0.6 million tonnes were landed to 2000, when 3.3 million tonnes were landed. We show that the MTI is steadily decreasing in all 13 Indian States and Union Territories, at rates averaging 0.058 trophic level per decade, about the same as in other parts of the world. This decline, however, is not due to the sequential addition of newly exploited species of low trophic level to the multi-species catch from which mean trophic level is calculated. Rather, the MTI values were computed after exclusion of species with trophic levels lower than 3.25. Notably, this excluded Indian oil sardine and penaeid shrimps, the catch of which grew enormously in the 1980s.

What has to date maintained the landings of higher trophic level fish in India has been the geographic expansion of the fisheries, which, until the early 1970s, exploited only waters immediately under the coast, while they now reaches to the edges of the continental shelf and beyond. This expansion is quantified here through a 'spatial expansion factor', based on a re-interpretation of the Fishing-in-Balance index. This index was proposed earlier to analyse, in an ecosystem context, the interrelationship between mean trophic level and magnitude of the catch, and the trophic transfer efficiency among trophic levels of the food web. The FiB index is shown here to allow, under some specific assumptions about productivity of the exploited areas, inferences on the spatial behavior of fisheries. Based on the newly formulated spatial expansion factor, it is suggested that the Indian shelf fisheries, covered by 2000 about 4 times the area they covered in 1970. However, this expansion had apparently met its natural limits, and catches can be expected to stagnate and ultimately decline, with serious consequences for the marine fisheries sector and consumers in India.

Keywords: Mean Trophic Level; Fishing-in-Balance index; India; Fishing down marine food webs; Sustainability indicators

1. Introduction

Lately, the sustainability of fisheries has raised widespread concerns, and ecosystem-based approaches have been proposed to manage fisheries (Jennings and Kaiser, 1998; Pikitch et al., 2004). However, concepts such as 'ecosystem health' are difficult to translate into operational objectives that can be directly used for policy making (Larkin, 1996). Therefore, there is a need for predictive indicators that can be easily parameterized using easily accessible data, while communicating with a single number a variety of complex processes occurring within an ecosystem (Christensen, 2000; Murawski, 2000; Pauly and Watson, 2005). One such indicator is the Marine Trophic Index (MTI), endorsed in 2004 for "immediate testing" by the parties (including India) of the Convention for Biological Diversity (CBD, 2004). The MTI is the CBD's name for the mean trophic level of fisheries catches, introduced by Pauly et al. (1998a) as an indicator of fishing impact on aquatic ecosystems. The rationale of this indicator, which quantifies a process now widely known as 'fishing down marine food webs' is that fisheries, upon depletion of the large, high-TL species they initially target, shift to small, low-TL species. This fishing down effect has been demonstrated in various parts of the world, such as Thailand (Christensen,

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doi:10.1016/j.fishres.2007.10.022

1998), Canada (Pauly et al., 2001), Greece (Stergiou and Koulouris, 2000), Iceland (Valtýsson and Pauly, 2003), the North Sea (Furness, 2002) and others (Pauly and Palomares, 2005; see also the MTI routine available for any country at www.seaaroundus.org).

The ubiquity of the fishing down effect is now well established; thus, it is appropriate to focus on second-orders effects not previously dealt with. Pauly et al. (1998b, 2000) and Pauly and Palomares (2001, 2005) have already dealt with the ontogenic, and spatial and taxonomic overaggregation effects suggested by Caddy et al. (1998) as potential problems for 'fishing down'. This study on Indian fisheries addresses the contention by Essington et al. (2006) that declining trophic levels are not in themselves a worrying phenomenon, because they are generally due to new species with low trophic levels being added to fisheries' catches, and, outside of the North Atlantic, not due to declining catches of higher trophic level fish.

As it turns out, this contention of Essington et al. (2006) can be dealt with in the same manner as the claim of Caddy et al. (1998) that fishing down often will be an artifact of 'bottom up effects' (primary productivity increases, which would increase the biomass and hence catches of low trophic-level fishes): by computing mean trophic levels after excluding fish species with low trophic level. Thus, following Pauly and Watson (2005), we define $^{\mathrm{cutoff}}$MTI, where 'cutoff' refers to the trophic level below which species or groups are dropped from the analysis to emphasize changes in the relative abundance of the high-TL fishes. Here, we have used a cut off of 3.25 to eliminate the masking effect of highly variable and abundant small pelagic fishes (also see Section 2).

Our domain of application is the marine fisheries of India. Because accurate catch time series data are essential for the MTI (Pauly and Watson, 2005), we begin with an account of how we assembled and edited the time series that were analyzed. Then, we present the Fishing-in-Balance (FiB) index, which enables us to assess whether a fishery is balanced ecologically or not based on transfer efficiencies between trophic levels (Pauly et al., 2000), and a new 'spatial expansion factor' allowing inferences on spatial extension of the fisheries. We conclude with the application of these indicators to the fisheries of India, and to those of each of her States (under the jurisdiction of state government) and Union Territories (under direct control of the federal government).

2. Material and methods

2.1. Catch and landing statistics

The landing data (which always pertain to weight in tonnes, or t, i.e., metric ton, corresponding to 1000 kg) for each maritime State (Gujarat, Maharashtra, Goa, Karnataka and Kerala on the west coast; and Tamil Nadu, Andhra Pradesh, Orissa and West Bengal on the east coast) and Union Territories (Lakshadweep and Daman and Diu on the west coast and Pondicherry, and Andaman and Nicobar Islands on the east coast) of India

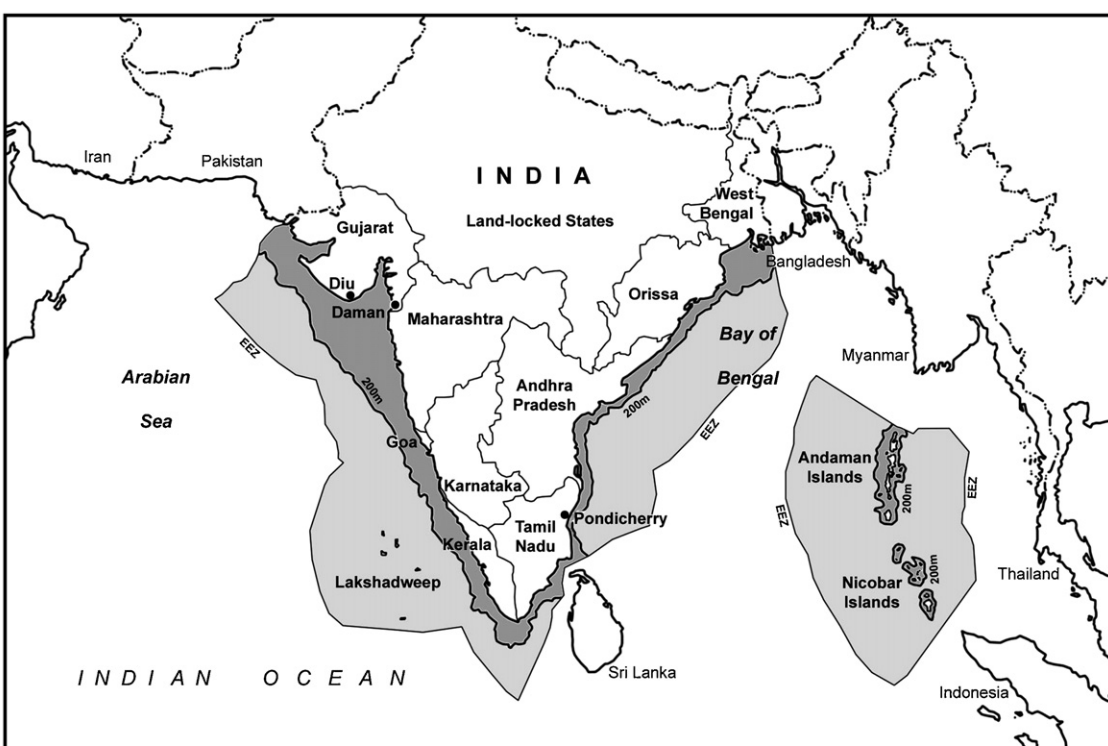

Fig. 1. The maritime States and Union Territories of India, from Gujarat in the Northwest (Arabian Sea) to the Andaman and Nicobar Islands in the Southeast (Bay of Bengal). The shelf (dark grey) and its 200 m depth limits are also shown, along with the rest of the Indian EEZ (light grey; from the Global Maritime Database, www.gd-ais.com).

Table 1
List of 28 broad functional groups (except ‘miscellaneous’), with further sub-divisions at Family, Genus and Species level and Trophic Levels (TLs) used in the analysis

Functional groups	Sub-groups	TL
Elasmobranchs	Sharks, skates, skates	3.7–4.2
Eels		4.1
Catfishes		3.9
Clupeids	Wolf herring, oil sardine, other sardines, hilsa shad, other shads, anchovies (*Anchoviella*, *Thrissocles*), other clupeids	2.0–4.5
Bombay duck		4.3
Lizard fishes		4.4
Half beaks and full beaks		3.4
Flying fishes		3.8
Perches	Rock cods, snappers, pig face breams, threadfin breams, other perches	3.4–4.1
Goatfishes		3.5
Threadfins		4.1
Croakers		4
Ribbon fishes		4.3
Jacks and their relatives	Horse mackerel, Scads, leather-jackets (*Trachynotus*), other carangids (*Coryphaena*, *Elacate*)	3.6–4.5
Silverbellies	*Leiognathus*, *Gazza*	2.9–3.7
Big jawed jumper		4.0
Pomfrets	Black pomfret, silver pomfret, Chinese pomfret	3.0
Mackerel	Indian mackerel, other mackerels	3.1
Seer fishes	*S. commersoni*, *S. guttatus*, *S. lineolatus*, *Acanthocybium* spp.	4.2–4.5
Tunas	*E. affinis*, *Auxis* spp., *K. pelamis*, *T. tonggol*, other tunnies	4.1–4.5
Bill fishes		4.5
Barracudas		4.5
Mullets		2.1
Unicorn cod		3.3
Flatfishes	Halibut, flounders, soles	
Crustaceans	Penaeid prawns, non-penaeid prawns, crabs, lobsters, stomatopods	2.7–3.1
Molluscs		2.0
Cephalopods		3.6

(Fig. 1) were compiled for the period 1950–2000. The data thus assembled from these 13 geographical regions were aggregated into 29 broad taxonomic categories (Table 1), with further sub-divisions into sub-groups at Family, Genus and Species level to total of 65 statistical categories, which were used in all analyses, through a common template applied to all States and Union Territories. This template corresponds, in its main features, to the format for landing statistics published by Central Marine Fisheries Research Institute’s (CMFRI), India’s premier fisheries research institution (for details, see Bhathal, 2005; e-copy available at http://www.fisheries.ubc.ca/publications/reports/report13_5.php).

The statistical data were compiled mainly from reports of CMFRI, complemented by miscellaneous publications by state research institutes and other Indian institutions, gathered during a field visit by the first author in July 2003. The various datasets in these documents were made coherent and mutually compatible using a series of procedures (discussed below) designed to obtaining a dataset not grossly biased by unrealistic observation of ‘zero’ catches (Pauly, 1998; Zeller et al., 2006). We deal later with the fact that only parts of the assembled time series (i.e., often excluding the 1950s, and the period from 1994 to 2000) can be used for MTI and other analyses. Note that, in any case, the procedures – including extrapolations – that were used here cannot have generated the trends in MTI and other changes reported on below.

The steps used were as follows:

(a) Missing catch and catch compositions in State and Union Territories: for the early years covered here, only total catches or catches by major groups were available for some States or Union Territories. In such cases, the species breakdown of first year with species specific catch composition data for the area in question was extrapolated backwards to 1950, while adjusted for the available total (see Bhathal, 2005). Also, in a few cases, the total catch for a period later than 1950 had to be extrapolated back to that year. An example is provided by the Lakshadweep, whose fisheries department came in existence in 1960. The very low catch of 1960, and its composition could be extrapolated backward, because we knew, based on Raghavan and Shanmughnam (1993), that the period up to 1960 had seen no change in the then exclusively small-scale fisheries of the area (Bhathal, 2005);

(b) Interpolation of missing species or groups: in years when (groups of) species at lower taxonomic level (sharks, rays) were not recorded in catch data, and were replaced for a short period by a higher level group (e.g., ‘selachians’), the higher level group was disaggregated into the lower level groups by interpolating between the years that gave detailed composition, while maintaining the higher group’s total. Interpolation was also performed when a previously abundant species suddenly dropped to zero, only to reappear a few years later, on the assumption that it had continued to be caught, but was reported as part of the ‘miscellaneous’ group (see below for conservation of mass);

(c) Reduction of the ‘miscellaneous’ group: about 4% of the over 70 million tonnes (cumulatively) caught since 1950 were reported in a ‘miscellaneous’ category. George et al. (1981) reported that the ‘miscellaneous’ group in Indian statistics generally includes low value fish of small size. Sujatha (1996) has shown that the low value fish catch of the trawl fishery off Vishakhapatnam (Andhra Pradesh) consists largely (67–94%) of the juveniles of exploited species. Similarly, Puthra et al. (1998) found that trawlers operating from 1988 to 1993 off the Veraval coast in Gujarat caught up to 52% of juveniles. Based on this and on similar information from other sources (Sivasubramaniam, 1990; Gordon, 1991; Rohit et al., 1993; Puthra and Manoharadoss, 1996; Salgrama, 1999), the miscellaneous group was reduced in two steps: (i) we used this group as a source of catch for abundant species that had suddenly, and for a few years, dropped from the catch statistics [as happens frequently in Indian statistics, see (b)]; (ii) the remaining miscellaneous groups were assigned to low-value demersal fish and invertebrate taxa in proportion to their contribution to the total catch;

(d) Discarding by the mechanized fleet: the large shrimp trawlers which, since 1972, operate mostly from Vishakapatnam, usually do not report their discarded fish by-catch to the designated institutes (Srinath, M., CMFRI, personal communication, April, 2004). A shrimp to by-catch ratio of 1:15 (Gordon, 1991) was used to estimate the fish by-catch from prawn landings (or average shrimp catch per vessel and total number of vessels; Bhathal, 2005). Of these, the high-value species (e.g., pomfrets, mullets, cephalopods), making up 30% of the by-catch is retained and eventually enter the landing statistics. The other 70% – mainly small demersal fishes – are discarded. Here, this by-catch was assumed to consist of low-value demersal species (groups) named in the statistics of the States where these trawlers operate. Thus, the by-catch was added to these species and groups (details in Bhathal, 2005). Discards by mechanized vessels other than large shrimp trawlers occurs (Gordon, 1991), but appears to be low, in the order of 2% (George et al., 1981). Here, it is assumed that this 2% figure, again consisting of low-value fishes, applies from 1970 onward, in all States and Union Territories (see Bhathal, 2005).

2.2. *Trophic levels and the MTI*

The fractional trophic levels (TL; Odum and Heald, 1975; Christensen and Pauly, 1992) used here are based on the diet composition data and on the equation:

$$\mathrm{TL}_i = 1 + \sum(\mathrm{DC}_{ij} \cdot \mathrm{TL}_j) \quad (1)$$

where TL_i is the trophic level of species i, DC_{ij} is the proportion of prey species j in the diet of species i and TL_j is the trophic level of prey species j. The primary producers (i.e., plants) and detritus are assigned a definitional TL of 1.

TL values for 320 commercially important fish species were obtained mainly from FishBase (www.fishbase.org). Values for genera and higher groups were taken as the mean TL of constituent species. If more than one TL estimate was available for any species (or of species group), the median of all available values was used. For invertebrate taxa, the estimates were taken mostly from the *Sea Around Us* Project database (see www.seaaroundus.org), and the ‘ISCCAAP Table’ of FishBase 2000 (Froese and Pauly, 2000); additional data sources for some TL values that were recomputed are given in Bhathal (2005). For example, the trophic level of *Rastrelliger kanagurta* (Indian mackerel) was re-estimated based on their diet composition given in local sources (Rao, 1967).

Values of the Marine Trophic Index (MTI) were calculated for each year by weighting the TL of all species (or higher taxa) by their catches, i.e.,

$$\mathrm{MTI}_k = \frac{\sum Y_{ik} \cdot \mathrm{TL}_i}{\sum Y_{ik}} \quad (2)$$

where TL_i is the trophic level of species (groups) i in year k, and Y_{ik} is their catches (=landings + discards).

In order for our analyses to be focused on neritic (shelf) ecosystems, tuna and billfishes, i.e., oceanic fishes, were omitted from the computation of the MTI and related statistics. This avoided the spatial overaggregation discussed in Pauly and Palomares (2005).

MTI values were computed twice for each Indian State and Union Territory, for 1950–2000: once for the entire neritic catch and a second time excluding all species (groups) with TL < 3.25, following Pauly and Watson (2005). These estimates of $^{3.25}$MTI emphasize changes in the relative abundance of medium and high-TL species, and ignore low-TL species. Then, regression analyses were performed, i.e., regression lines were fitted to MTI (i.e., mean TL) series against time (and correspondingly for the correlations). For each regression line, a different starting point was selected, representing the start of visible part of the fishing down trend (see Table 2). Different starting points were used because: (1) the fishing down effect is detectable only after fishing pressure has reached some critical level, varying between states and (2) in earlier decades (dataset starts from 1950) the fisheries statistics were insufficiently detailed. Further, the data from 1994 to 2000 were not included in regression analysis, for two reasons; (1) the data collecting system in India have deteriorated in the last decade of the 20th century, and (2) the data clearly deviate, on most plots from the trends suggested by the earlier years (see below).

2.3. *The Fishing-in-Balance (FiB) index and its spatial extension*

Marine ecosystems operate as pyramids wherein the primary production generated at TL one is moved up toward the higher TL, i.e., to the consumers. However, not all the energy embodied in food consumed is transferred into predator biomass, because a huge fraction is used for the maintenance, reproduction and other

Table 2
Rate of trophic level decline in the fisheries catch of India's States and Union Territories

Geographical entity		Start of regression	TL decline (all shelf spp.)	TL decline (spp w/TL > 3.25)	r^2	Corr. (r)
India		1964	No clear trend	0.058	0.858	−0.926
A	Gujarat	1961	0.120	0.075	0.840	−0.917
B	Daman and Diu	1960	No clear trend	0.043	0.432	−0.657
C	Goa	1973	0.024	0.091	0.643	−0.801
D	Maharashtra	1955	No clear trend	0.044	0.629	−0.793
E	Karnataka	1962	No clear trend	0.085	0.821	−0.905
F	Kerala	1964	No clear trend	0.080	0.555	−0.744
G	Lakshadweep	1965	0.055	0.055	0.707	−0.841
L	Tamil Nadu	1956	0.128	0.055	0.818	−0.904
K	Pondicherry	1955	0.123	0.024	0.194	−0.441
J	Andhra Pradesh	1968	0.036	0.028	0.333	−0.576
I	Orissa	1967	No clear trend	0.032	0.301	−0.548
H	West Bengal	1967	0.031	0.039	0.338	−0.581
M	Andaman and Nicobar Islands	1950	0.076	0.011	0.135	−0.367

The fishing down trends, were fitted only until 1993 (see text). The first column of 'TL declines' (per decade) pertains to mean trophic levels including all neritic groups. The second column of TL declines (per decade) pertains only to neritic groups with TL > 3.25. Coefficient of determination and correlation coefficients are given only for the latter (see also Figs. 3 and 2B).

activities of the animals in the systems (Pauly and Christensen, 1995). Therefore, deliberately fishing down should enable more of an ecosystem's biological production to be captured by fishing. However, if waste, here as well, is to be avoided, any decline in the mean TL of the fisheries catches should be matched by an ecologically appropriate increase in these catches. The appropriateness of that increase is determined by the transfer efficiency (TE) between TLs. For example, if TE is 0.1, then decline of one TL should correspond to ten fold increase of catch.

Thus, a Fishing-in-Balance index can be defined which:

- will remain constant (remains = 0) if TL changes are matched by 'ecologically correct' changes in catch, given the TE;
- will increase (>0) if: either 'bottom up effect' occurs, e.g., increase in primary production in the Mediterranean (which triggered Caddy et al.'s concerns), or if a geographic expansion of the fishery occurs, and the 'ecosystem' that is exploited by the fishery has been in fact expanded;
- will decrease (<0) if discarding occurs that is not considered in the 'catches', or if the fisheries removes so much biomass from the ecosystem that its functioning is impaired.

A Fishing-in-Balance index meeting these criteria is:

$$\mathrm{FiB}_k = \log\left[Y_k \cdot \left(\frac{1}{\mathrm{TE}}\right)^{\mathrm{TL}_k}\right] - \log\left[Y_0 \cdot \left(\frac{1}{\mathrm{TE}}\right)^{\mathrm{TL}_0}\right] \qquad (3)$$

where Y_k is the catch in year k, TL_k and TL_0 the mean trophic level of the catch in year k and 0, respectively (here computed for all neritic species and groups), TE is the mean transfer efficiency, and 0 refers to any year used as a baseline to normalize the index (Pauly et al., 2000). Here TE is set at 0.1, as estimated as a reasonable average for marine systems by Pauly and Christensen (1995) on the basis of 48 published ecosystem models; the choice of different value, if realistic ($0.05 < \mathrm{TE} < 0.15$), does not alter any of the conclusion below.

The FiB index, as defined above, and with TE = 0.1, has the property of staying constant if catch increases by factor of ten for each decline of 1 trophic level. This is due to the fact that, in the absence of geographic expansion or contraction, and with an ecosystem that has maintained its structural integrity, for the fisheries to be moving down the food web should result in increased catches (and conversely for increasing TL). Therefore, the FiB index will increase only if catches increase faster than would be predicted by TL declines and will decrease if increasing catches fail to compensate for a decrease in TL.

Examination of various case histories (Pauly et al., 2001; Pauly and Palomares, 2005) shows that the FiB index increases where geographic expansion of the fisheries is known to have occurred. This begs the question whether consideration of this expansion can be made explicit in a form of the FiB index normalized for the area fished in a given year (A_k), relative to the area covered in the baseline year (A_0). This leads to a modified equation for an area-weighted FiB index, which could be called the Balance-in-Fishing (BiF) index:

$$\mathrm{BiF}_k = \log\left[Y_k \cdot \left(\frac{1}{\mathrm{TE}}\right)^{\mathrm{TL}_k} \cdot A_0\right] - \log\left[Y_0 \cdot \left(\frac{1}{\mathrm{TE}}\right)^{\mathrm{TL}_0} \cdot A_k\right] \qquad (4)$$

Thus, we can define what might be called a spatial 'Expansion factor' (A_k/A_0):

$$\frac{A_k}{A_0} = 10^{(\mathrm{FiB}_k - \mathrm{BiF}_k)} \qquad (5)$$

Given accurate catch data, correct estimates of TE, TL_i and A_k, the value of the BiF index should (by definition) remain zero through time, we can interpret Eq. (5) as implying an expansion with regard to year 0 (and area A_0) that can be quantified using:

$$\text{Expansion factor}_k = 10^{\mathrm{FiB}_k} \qquad (6)$$

Eq. (6) holds, however, if the expansion involved areas with the same productivity as that of the area exploited in the baseline year (i.e., A_k can support, on a per-area basis, the same catch as A_0). Thus, whenever, in term of productivity, $A_k > A_0$, the expansion factor is underestimated.

This assumption, through likely never to be strictly met in practice, may not be unrealistic when comparing successive depth ranges of a smoothly sloping shelf, as occurs around much of India (Chauhan et al., 2000).

3. Results

Fig. 2A gives our summary of Indian marine catches from 1950 to 2000, with emphasis on the categories relevant to our analysis below, i.e., the distinction between neritic fishes with TL lower than 3.25, those above, and tuna and billfishes, here not further mentioned. As might be seen, catches increased from 0.6 to 3.3 million tonnes, most of the increase being due to lower TL level fishes, notably Oil sardine.

Figs. 2B and 3 document that fishing down is occurring in Indian marine waters, both on the east and the west coast. It is more pronounced on the west coast, which contributes 72% of India's total catch. However, this becomes evident only because we excluded low TL species from the analysis, i.e., we used $^{3.25}$MTI (Figs. 2B and 3, Table 2). The estimated average rate of MTI decline (0.058 TL per decade; Table 2) is about average for the world as a whole (Pauly et al., 1998a; Pauly and Palomares, 2005), but higher than the rate of 0.04 estimated for India by Vivekanandan et al. (2005) (see below).

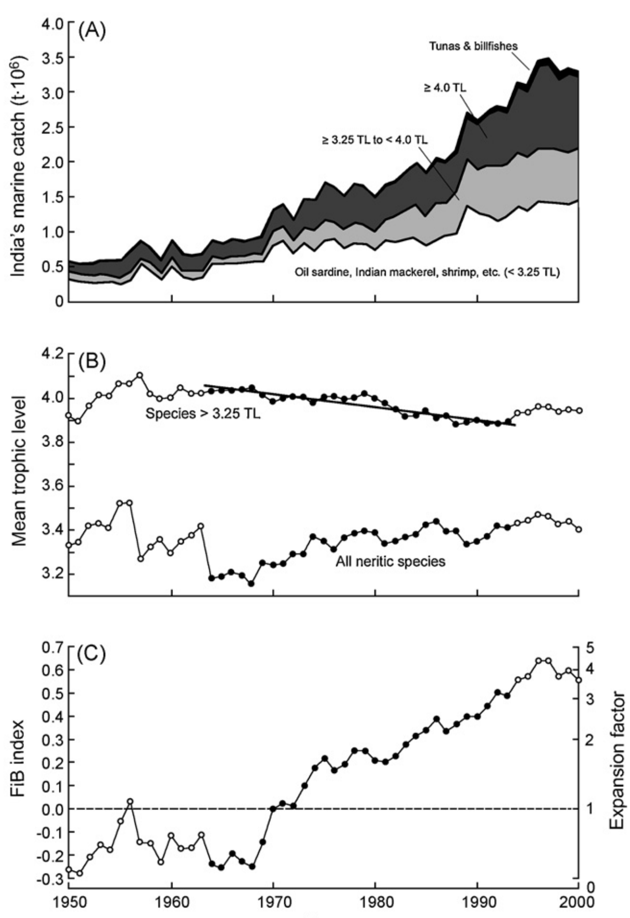

Fig. 2. Basic trends in Indian fisheries, from 1950 to 2000 (open circles represent data points not included in the analysis); (a) catch (million tonnes); (b) mean trophic level of the catch (TL) and cutoff mean trophic level of the catch (3.25 MTI); (c) Fishing-in-Balance (FiB) index and Expansion factor illustrating spatial expansion of the fishery.

Figs. 2C and 4, which show FiB index trends for India and each of its maritime States and Union Territories, suggest that the increase of catch that occurred in Indian waters from the early 1970s on was well in excess of what could have been obtained by continuing to 'fish down the food web' within the narrow range of coastal waters then exploited. And in fact, we do know that the early 1970s were the times when industrialized fishing in India began in earnest (PCGI, 1974). This allowed a wider range of depths, and ultimately the entire shelf, to be exploited.

Assuming that the entire shelf, i.e., the area down to 200 m surrounding India and adjacent islands (~372,000 km^2), was exploited in 2000, the approximately fourfold expansion of the area covered by fisheries from 1970 to 2000 suggested by Fig. 2C would imply that the area fished from 1950 to 1970 was 372,000 km^2/4 = 93,000 km^2, which is the area of the inner shelf down to the 20 m isobath. This is reasonable, as the fishing crafts and gear then deployed were overwhelmingly small-scale, and restricted to coastal areas (Srinath, 2003). This would suggests that the re-interpretation presented here (see Fig. 2C) of the FiB index as an indicator of spatial expansion may be viable.

4. Discussion

As discussed above, Indian marine catches have increased over time but this went along with a decline in the MTI for all of India, which becomes clear after the masking effect of highly fluctuating low TL species is removed. The preliminary analysis of Vivekanandan et al. (2005) led to equivocal results, i.e., that fishing down is occurring in Indian waters, but only on the eastern coast, at the rate of 0.04 TL per decade. This is due to inclusion of highly variable species at low TL. In addition, our analysis was done at a finer spatial scale, i.e., each of the individual states and UT's were examined to reflect the actual extent of fisheries impact on the local ecosystem. Finally, we included in our analysis discarded by-catch and the catches of industrial vessels.

The demonstration that the fishing down phenomenon becomes more visible after applying a cut off level of 3.25 TL implies that it is not due to 'bottom up effects' (Caddy et al., 1998). Moreover, this also shows that fishing down is not due, at least in the Indian case, to "successive addition" of low-TL species to the mix exploited by the fisheries (Essington et al., 2006).

The trend (regression) analyses show relatively tight fits, reflected in high correlation coefficients (Table 2). While this indicate that the trends in question are smooth, the absolute value of the correlation coefficients do not mean much, as the choice of the first and last points included in the trend analysis was determined by the straightness of the curves thus obtained. Our interpolations and extrapolations, on the other hand, had little or no influence on the results, as they most often covered the earliest years, which were omitted from most trend analy-

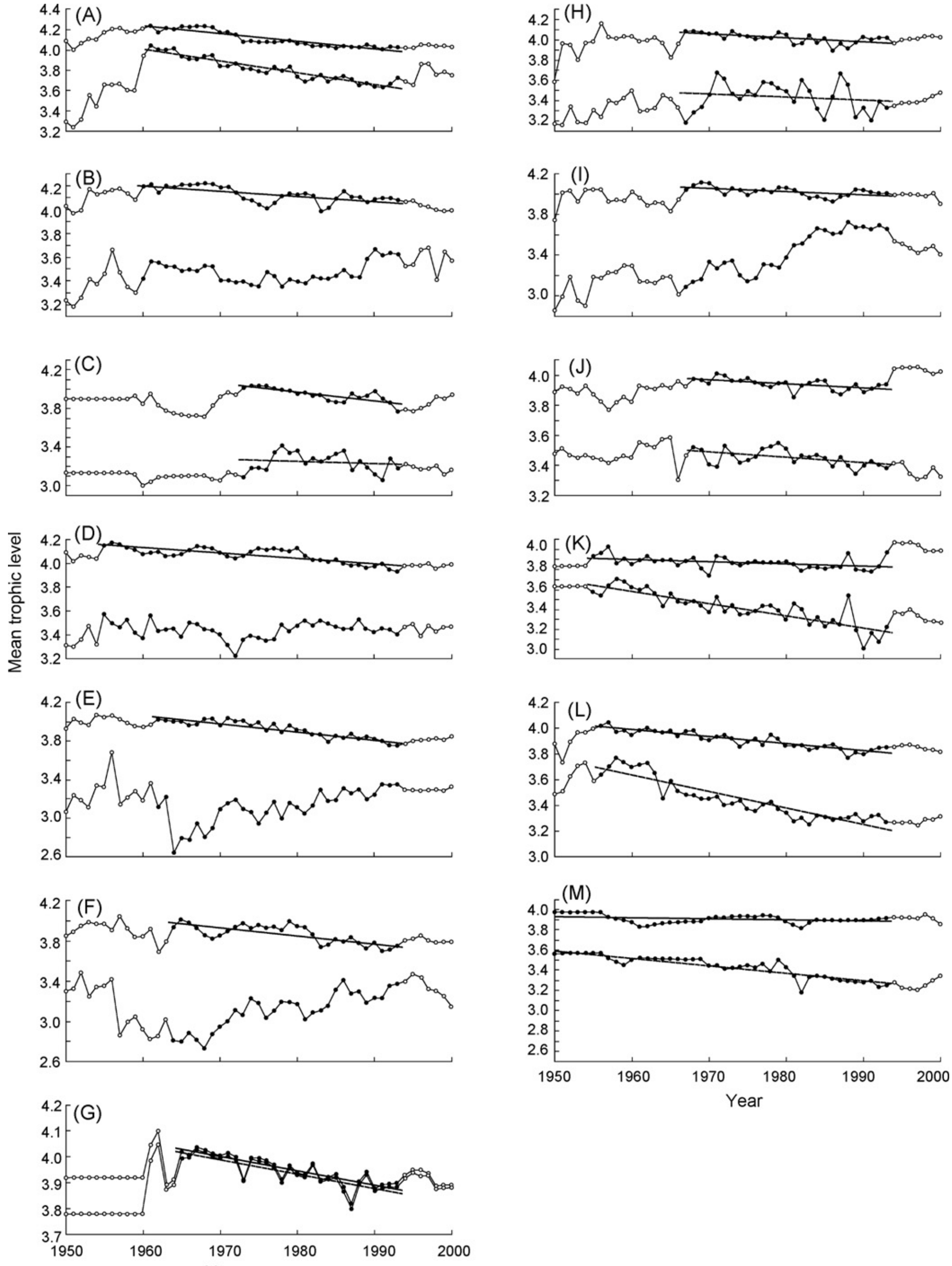

Fig. 3. Trends in mean trophic level and cutoff mean trophic level (3.25 MTI) of landings in Indian States and Union Territories, from 1950 to 2000 (open circles represent data points not included in the analysis). (A) Gujarat, (B) Daman and Diu, (C) Goa, (D) Maharashtra, (E) Karnataka, (F) Kerala, (G) Lakshadweep, (H) West Bengal, (I) Orissa, (J) Andhra Pradesh, (K) Pondicherry, (L) Tamil Nadu and, (M) Andaman and Nicobar Islands.

sis. Also, we recall that backward extrapolations of, e.g., catch compositions occurring in the 1960s back to the 1950s cannot generate variable MTI values, and hence contribute to a trend thereof. Rather, such extrapolations will have the contrary effect of masking a trend that might have been present. We are thus confident that the MTI trends presented here are not artifacts of our pre-processing of the catch data.

On the other hand, the straightness of MTI trends, from their starting point to the year 1993, suggests that the catch data from 1994 to 2000, which generally deviate from the lines' projection to 2000, are less reliable than those collected before. This is in agreement with the fact that from 1994 on, national catch statistics were based on methods less accurate than the rigorous statistical sampling design previously used by CMFRI. This problem, which affects other sector besides fisheries[2], has led

[2] Based on the paper, "Infectious credulity: strategic behavior in the manufacture and use of data" presented by Herrere, Y.M., and Kapur, D. at annual meeting (2000) of the American Political Science Association in Boston.

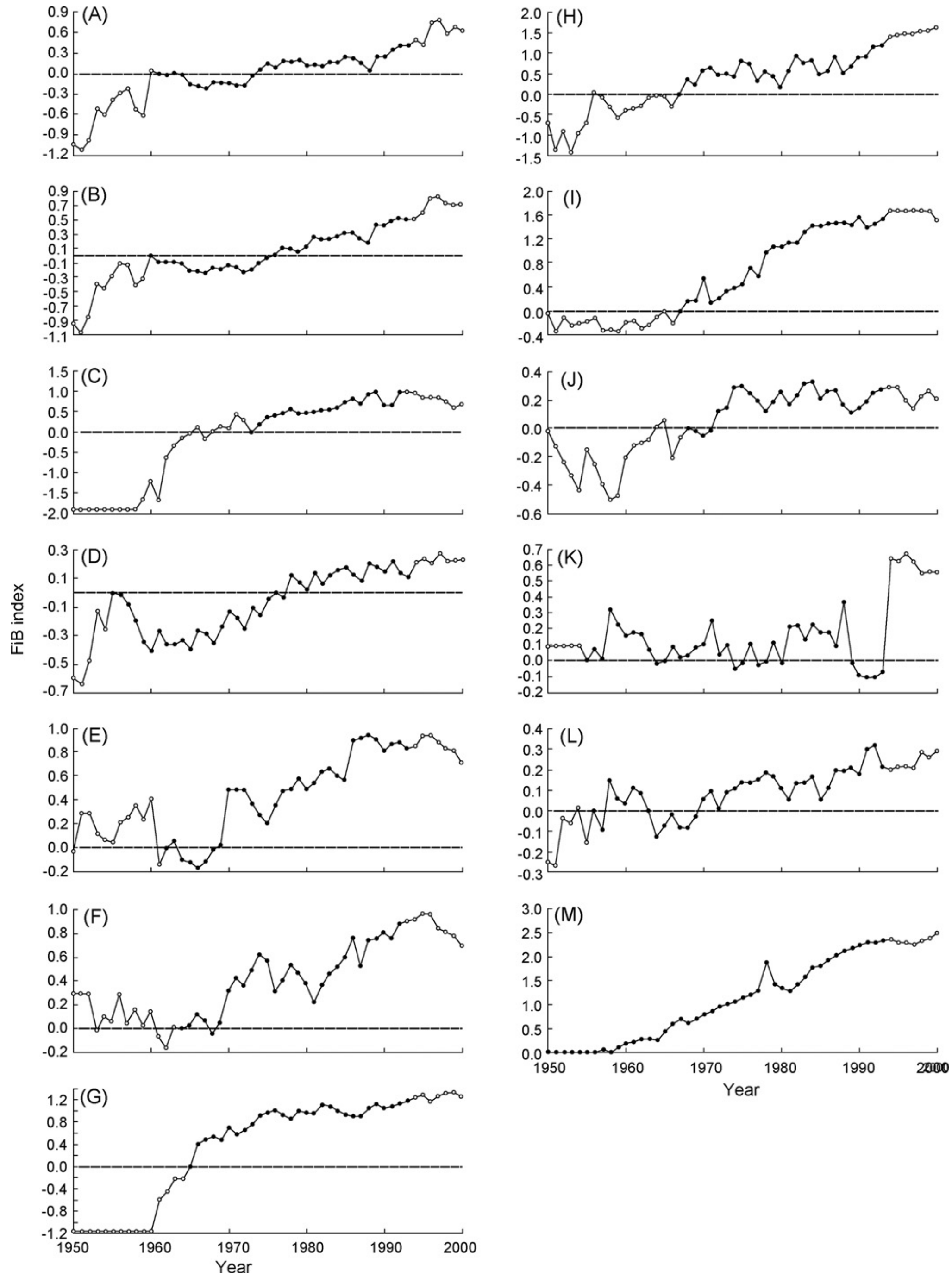

Fig. 4. Trends of the 'Fishing-in-Balance (FiB) index' of fisheries in Indian States and Union Territories from 1950 to 2000 (open circles represent data points not included in the analysis) (A) Gujarat, (B) Daman and Diu, (C) Goa, (D) Maharashtra, (E) Karnataka, (F) Kerala, (G) Lakshadweep, (H) West Bengal, (I) Orissa, (J) Andhra Pradesh, (K) Pondicherry, (L) Tamil Nadu, and (M) Andaman and Nicobar Islands.

to a deterioration of Indian production statistics since the mid 1990s. This suggests, although we do no want to overemphasize the point, that MTI trend lines may be used, under certain circumstances, to highlight otherwise undetectable anomalies in the underlying catch data.

The newly proposed spatial Expansion factor yielded results of the correct magnitude when applied to India, but it will need thorough testing before these results can be considered accurate, and the method used more widely.

In summary, it is apparent that Indian fisheries are not on a sustainable trajectory, and that the catch increases of the 1980 and 1990s were due to a spatial (offshore) expansion which, as the deep waters around India cannot be expected to be as productive as the shelf waters (Longhurst and Pauly, 1987), has now reached its natural limits. Therefore, current polices dedicated to further expansion of the fisheries sector need reconsideration, as they could have serious food security and economic implications in the near future.

Acknowledgements

We thank Dr. Derek Johnson, Dr. Pushpam Kumar, Dr. Mohan Joseph Modayil, Mr. Edwin Joseph, Mr. M. Nithyanandan, Mr. Naveen Rajashekar, Mr. Rajeev Raghavan, Dr. Reema Devi, Dr. E Venkataraman and many others for their assistance in locating and making accessible reports with useful statistics. We also thank Dr. Jackie Alder, Dr. Rashid Sumaila, Dr. Amanda Vincent, Dr. Tony Pitcher and Mr. Harjeet Bhathal for their input to various aspects of this project. This study is an output of the *Sea Around Us* Project, initiated and supported by the Pew Charitable Trusts, Philadelphia.

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