Willemse, N.E. and D. Pauly 2004. Reconstruction and interpretation of marine fisheries catches from Namibian waters, 1950 to 2000. p. 99-112 In: U.R. Sumaila, D. Boyer, M.D. Skogen and S. I. Steinshamm (eds.). Namibia's fisheries: ecological, economic and social aspects. Eburon Academic Publishers, Amsterdam.

5 RECONSTRUCTION AND INTERPRETATION OF MARINE FISHERIES CATCHES FROM NAMIBIAN WATERS, 1950 TO 2000

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Abstract
Time series of catches taken by local and foreign fleets from Namibian waters were reconstructed for the period from 1950 to 2000 from a variety of published and unpublished sources. Examination of these time series demonstrated a gradual shift in catches from larger, long-lived piscivorous fish species to smaller, short-lived planktivorous fishes and invertebrates, which, as would be expected, reflects similar changes in the relative abundance of these species in the Namibian marine ecosystem. Similar results were obtained from the examination of trends in trophic-based indicators, which confirmed that the fishing down marine food web phenomenon occurs in Namibian waters. More precisely, three periods marking different trends and developmental stages of the fishery were identified, viz, an 'undeveloped' stage (1950-1964), marked by the dominance of southern African sardine, a 'developing/mature' stage, characterised by increased fishing effort, landings and diversification of target species (1965-1969), and a 'senescent' stage with declining ratios of piscivorous to planktivorous fishes and, more ominously, declining total landings (1970-2000). Some of the ecological ramifications of these findings are discussed, along with the need for ecosystem-based management of Namibia's marine fisheries.

INTRODUCTION

The concept of 'ecosystem-based fisheries management' is about two decades old, and widely discussed in the scientific literature, but it is still not

[*] We would like to thank the National Marine Information and Research Centre (NatMIRC), Ministry of Fisheries and Marine Resources (MFMR), Swakopmund for data and invaluable assistance. We would also like to thank M.L. Deng Palomares, D.C. Boyer, P. Cury and G. Bianchi for useful comments on the draft version. Nico E. Willemse thanks Jorge Santos, Norwegian College of Fishery Science, Tromsø, Norway, for his contribution toward the M.Sc. thesis upon which this chapter is based. Daniel Pauly thanks the Pew Charitable Trust for their support of the Sea Around Us Project.

part of the practice of fisheries management. One reason, clearly, is that it seems to imply a vast knowledge about the ecosystems in which the fisheries are embedded, and an excessive emphasis on conservation, to the detriment of a still perceived need for fisheries 'development', not only in mature fisheries such as Namibia, but particularly in developing countries.

Here we show that, on the contrary, inferences on the state of an exploited marine ecosystem can be derived from data that are not only straightforward to obtain, but are in fact required for the more traditional single-species approaches. Moreover, we suggest that by not considering ecosystem effects, fisheries managers increase the risk of deleterious changes in the ecosystem within which fisheries are embedded, all the way to their collapse (Pauly, 1998; Pauly *et al.,* 1998a).

The key data for both single-species and ecosystem-based approaches are long time series of catch data. These time series must refer to catches (i.e., the biomass of all organisms that are killed by fishing operations), rather than only landings (i.e., the part of the catch that is brought ashore), because it is through their catches that fisheries impact ecosystems. Further, the time series must be long, in order to incorporate contrast, and thus help identify the cause for change (Hilborn and Walters, 1992).

Namibia's history, in the last 50 years, was not conducive to the accumulation of such long time series of fisheries catch data. Hence, this contribution starts with a brief account of how such time series were assembled, both to support our studies, and to support other analyses of Namibian fisheries. The biology, and especially the trophic role, of major fish species in the Namibian marine ecosystem are then summarized. We conclude with a preliminary analysis of the resulting time series, i.e., we test for the occurrence in Namibian waters of the 'fishing down marine food webs' phenomenon originally described by Pauly *et al.* (1998a), through the examination of times series of mean trophic levels in the catches, as corroborated by an analysis of the ratio of piscivorous to planktivorous fishes (Caddy and Garibaldi, 2000), and of the FiB (fishing-in-balance) index of Pauly *et al.* (2000).

RECONSTRUCTION OF CATCHES FOR NAMIBIAN MARINE WATERS, 1950-2000

Data on landings (in metric tons, or 'tonnes') from Namibian waters were extracted primarily from Statistical Bulletins and other documents of the Madrid-based International Commission for the South Eastern Atlantic Fisheries (ICSEAF), which reported from 1971 on the activities of distant water fleets (DWF) operating off Namibia. Other data, notably early catch figures from 'South West Africa,' then under the administration of South Africa, were obtained from the Food and Agriculture Organisation (FAO) and South African fisheries statistics. Also, reports of the National Marine Information and Research Centre (NatMIRC; Ministry of Fisheries and Marine Resources, Namibia) and articles in scientific journals were searched for information. For example, Crawford *et al.* (1987) published landings data extracted from ICSEAF Statistical Bulletins, which also formed the basis of many subsequent studies (including by NatMIRC staff).

The fish species whose catch is documented here largely overlap with the species listed in statistical reports of the Ministry of Fisheries and Marine Resources (MFMR), Namibia, and include all groups that can be expected to impact, either as prey or as predator, on the structure and functioning of the Namibian marine ecosystem (see also Palomares and Pauly, this volume). Only those species whose landings are negligible (e.g., orange roughy, alfonsino, jacopever) were not explicitly considered here, though they are considered implicitly in the analysis of catch trends, through their inclusion in the 'mixed species' category.

Landings for the two *Merluccius* species caught off Namibia, *Merluccius capensis* and *M. paradoxus*, were combined, and treated as a single entity ('Cape hakes'), because the two species are not distinguished in catch records. The various species of tuna caught in Namibian waters were also aggregated (see below).

As the catch data assembled here largely resembled those published by Boyer and Hampton (2001), we abstain from presenting them here. They may be found, however, under 'Namibia' in the global catch database of the *Sea Around Us* Project (see *www.seaaroundus.org*).

BIOLOGY AND TROPHIC LEVELS OF MAJOR FISH SPECIES IN NAMIBIAN MARINE WATERS

We present here key features of major commercial and other species in Namibian waters, each of the brief accounts ending with the trophic level estimate (TL; see below for definition) we used to compute time series of mean TL, and with a one letter assignment (for fishes) to either piscivory (P) or planktivory (Z, see below). The TL values used here are updated, based on FishBase (Froese and Pauly, 2000; version of February 2004; see *www.fishbase.org*), and other sources (notably Heymans and Baird, 2000; Jarre-Teichmann *et al.,* 1998; and contributions in Payne *et al.,* 2001), and the preliminary estimates used in Willemse (2002) and Willemse and Pauly (2004).

The trophic levels of lobsters and crabs are based on estimates for related species in Eastern Canadian waters (Pauly *et al.,* 2001).

Tunas. - Seven species of tuna occur in Namibian waters, but only two are identified as important to the fisheries: albacore (*Thunnus alalunga)* dominate the pole fishery, while bigeye (*Thunnus obesus)* dominate the long-line fishery. The high market prices of tuna make up for their relatively low catches off Namibia (Manning, 1998).

Albacore, which can attain a fork length of 130 cm, are found between 10°S and 40°S in the South Atlantic, and spawn off Brazil just south of the equator and in the Central Atlantic, where the surface temperature of the water exceeds 24°C (Manning, 1998). Bigeye attain a fork length of 200 cm, and range across the Atlantic between 45°S and 45°N. Spawning occurs in the east central Atlantic, north of 5°N in the warmest season when the season surface temperature is above 24°C, and in the Gulf of Guinea (Manning, 1998).

Yellowfin (*Thunnus albacares)* can reach a fork length of over 200 cm and are preyed upon by toothed whales and billfishes (Bianchi *et al.,* 1993). This pelagic oceanic species is caught mainly by longlines at depth ranging from 200 to 300 m. Skipjack (*Katsuwonus pelamis)* attain a fork length of 108 cm and are distributed widely in all oceans. They are taken with purse seines, pole-and-line and longlines.

The food of these four tuna species is rather similar, and consists of a wide range or fish, notably sardine, anchovy, lanternfishes, cephalopods and crustaceans; cannibalism is also common (Bianchi *et al.,* 1993); TL = 4.4, P.

Southern African sardine. - The southern African sardine (*Sardinops sagax*) is a relatively short-lived species with a high reproductive capacity. Thus, like other small pelagics, this sardine fluctuates strongly in response to environmental changes, which impact on the early life history (Boyer, 1994). Spawning occurs north or south of the Lüderitz upwelling cell, as the cold, highly turbulent, weakly stratified water of this area is not conducive for larval development (Crawford *et al.,* 1987).

Younger sardine spawn in the warmer waters of the north, while the older ones spawn in the vicinity of Walvis Bay (Boyer and Hampton, 2001). Tagging studies demonstrated no movement of sardine from the Western Cape to Namibia and minimal movement of sardine to the Western Cape coast (Boyer *et al.,* 2001).

Juvenile sardine feed on zooplankton while the adults feed on phytoplankton and zooplankton (Boyer and Hampton, 2001; Bianchi *et al.,* 1993; van der Lingen, 1998); TL = 2.5, Z.

Cape anchovy. - The distribution and movement of Cape anchovy (*Engraulis capensis*) off Namibia used to be similar to that of sardine, but spawning was only significant north of Walvis Bay, with dense concentrations of larvae occurring beyond 100 km from the coast (Boyer and Hampton, 2001). The northern limit of anchovy is usually the southern edge of the Angola-Benguela front. Cape anchovy are caught in the purse-seine fishery (Manning, 1998).

Anchovy feed primarily on zooplankton, both as juveniles and adults (Boyer and Hampton, 2001); TL = 3.0, Z.

Cape horse mackerel ('Maasbanker'). - Juvenile horse mackerel (*Trachurus capensis*) are pelagic and live in waters <200 m deep to the age of two years (<20 cm) before they are recruited to the adult, semi-pelagic stock (Klingelhoeffer, 1994; Manning, 1998). They then move to deeper water, mainly north of Walvis Bay with dense concentrations between Cape Cross and the Kunene River. Adult horse mackerel, which may reach a length of up to 60 cm, spawn during both summer and winter, with peak activity between January and April (Klingelhoeffer, 1994).

While a small portion of juvenile horse mackerel are used for human consumption, most are reduced to fish meal (Manning, 1998). On the other hand, 60% of the catch of adults is frozen whole, while the remainder is processed into fish meal or dried and salted.

Juvenile horse mackerel feed on zooplankton, while the adults feed mainly on euphausiids shrimp (krill), with pelagic goby, lantern fish and juvenile horse mackerel making up the remainder of the diet (Klingelhoeffer, 1994). Juvenile TL = 3.1, Z; adults: TL = 3.5, P.

Pelagic goby. - The 3 to 6 cm juveniles of the Pelagic goby (*Sufflogobius bibarbatus)* live close to the sea surface, while the adults, ranging from 7 to 15 cm, live in deeper water. According to Crawford *et al.* (1987), pelagic gobies are consumed by most piscivorous fish species, and by seabirds and marine mammals, suggesting that pelagic goby play a major role as prey species in Namibian waters. This species is occasionally targeted by purse-seines, and is sometimes caught in bottom trawls (Bianchi *et al.,* 1993), though not in quantities reflecting their abundance in the ecosystem, a theme to which we return further below.

Pelagic goby are phytoplankton feeders; TL = 2.2, Z.

Round herring. - Round herring (*Etrumeus whiteheadi)* also known as redeye, reach about 20 cm, and are caught in purse seines and trawls at depths which may range from 10 to 200 m, but usually less than 100 m.

Round herring feed mainly on large zooplankton; TL = 3.4, Z.

Angelfish. - The Angelfish (*Brama brama)* occur from the sea surface to a depth of 1000 m, where it is preyed upon by billfish and tuna, and commonly caught by trawling (Bianchi *et al.,* 1993).

Angelfish feed on myctophids and other small fishes, euphausiids and cephalopods; TL = 4.1, P.

Cape hakes. - Two species of hake are caught in Namibian waters: *M. capensis,* or Cape hake (also known as shallow water hake), occurring mainly between the 200 and 350 m isobaths and constituting the bulk of the hake catch; and *M. paradoxus* or deepwater hake, occurring typically deeper, around the 350 m isobath in the south, and making up an average of thirty per cent (30%) of the catch between 1990 and 1996. A third species, of no commercial importance, *M. polli* or Benguela hake, is found in northern Namibian waters (Manning, 1998).

Young hake occur in the inshore waters at depths between 25 and 100 m for close to one year before migrating to deeper waters (Hamukuaya, 1994). Hake are targeted by the bottom trawl fishery, Namibia's most important fishery in terms of value since the mid-1990s.

Hake are predominantly piscivorous, and feed on both demersal and semi-pelagic fishes, which they catch staying close to the bottom during the day, and in mid-water at night; TL = 4.75, P.

John Dory. - John Dory (*Zeus faber)* is a demersal species ranging from coastal water to depths of 400 m; they are caught mainly by bottom trawls.

The food of John Dory consists mainly of schooling bony fishes, with occasional crustaceans and cephalopods (Bianchi *et al.,* 1993); TL = 4.5, P.

Snoek. - Snoek (*Thyrsites atun*) are pelagic in coastal waters, at temperatures between 13°C and 18°C. They are one of the dominant commercial fish species in Namibia and are fished with line gear (Bianchi *et al.,* 1993).

Snoek feed mainly on anchovy and sardine, but also on a variety of other organisms when these two species are scarce (Bianchi *et al.,* 1993); TL = 4.0, P.

Silver kob. - Silver kob (*Argyrosomus inodorus*) also known as kabeljou, can attain a length of 130 cm. They are primarily a coastal species, ranging from the surface to 150 m, but also occur at 400 m. Kob feed at night and/or in turbid waters, on a variety of crustacean species (Bianchi *et al.,* 1993).

Here, the method described in Froese and Pauly (2000, Box 26) was applied to obtain an estimate of TL (via a size adjustment) based on that of a close relative, *Argyrosomus hololepidotus,* for which it has often been mistaken. As well, the food items for *A. inodorus* and *A. hololepidotus* in FishBase and in Bianchi *et al.* (1993) resembled each other sufficiently for the trophic level estimate obtained for the latter to be used for the former species. Thus, TL = 4.3, P.

West Coast steenbras. - The West Coast steenbras (*Lithognathus aureti)* can reach up to 100 cm, and live in schools near the coast usually over sandy sea bottoms.

Steenbras feed on sand mussels, crabs and worms (Bianchi *et al.,* 1993); TL = 3.4, Z.

Cape monk. - Monk (*Lophius vomerinus)* reach maturity at 4 years at about 40 cm, but can reach a maximum length of 100 cm (Bianchi *et al.,* 1993). They occur on the deeper continental shelf and upper slope at depths between 200 m and 400 m, and are caught by bottom trawls and longlines. Monk are, with the tuna, one of the most valuable fish species of Namibia in terms of price per unit weight.

Monk ambush any small and large prey, up to their own size, but hake are their main food items (Boyer and Hampton, 2001); TL = 4.8, P.

Cape gurnard. - Cape gurnard (*Chelidonichthys capensis)* occur on the continental shelf between depths of 10 and 390 m, and are caught mainly in bottom trawls.

Cape gurnard feed mainly on small fishes (Bianchi *et al.,* 1993); TL = 4.3, P.

Other species. - We used the following settings for the other species in the catch database: chub mackerel: TL = 4.3, P; large eye dentex: TL = 3.7, Z; kinglip: TL = 4.4, P; Westcoast sole: TL = 3.5, Z (here treating small zoobenthos as if it were zooplankton); silver kob: TL = 4.3, P; panga and reds:TL = 3.9, Z; rock lobster: TL = 2.6 (not considered for P/Z computation); crabs: TL = 2.3 (not considered for P/Z computation); and 'Mixed species': not used in computation of mean TL.

DERIVATION OF TIME SERIES OF INDICES OF ECOSYSTEM STATES

Using catch data as a proxy to describe the underlying structure and dynamics of marine systems is not perfect. However, in the absence of more direct data, catch data are believed to broadly reflect the ecosystem from which the catches were made. Such data are frequently used for single-species stock assessment purposes (e.g. catch per unit of effort data) and have previously been used in other ecological studies (see Pauly, 1998). Therefore, while not perfect, we believe that these data are informative for our purposes and as such represent a cost-effective information for use in descriptions of the ecosystem status of the Namibian marine system.

Trophic levels (TL) express the number of steps a consumer organism is removed from the primary producers at the base of a food web, and can be defined by the equation:

$$TL_j = 1 + \sum_{j=1}^{n} DC_{ij} \cdot TL_j \tag{1}$$

where i is the predator, j the nth prey, and DC_{ij} is the fraction of j in the diet of i. TL assignment starts with detritus and plants, both with definitional TL value of 1.

The mean trophic level of the catch from Namibian waters was computed for each year from 1950 to 2000 landings, using

$$\overline{TL_k} = \cdot \sum_{i=1}^{m} Y_i k \cdot TL_i \Big/ \sum_{i=1}^{m} Y_i k \tag{2}$$

where Y_{ik} is the landings of species i in year k and TL_i is its trophic level, implying that the mean trophic level thus obtained is weighted by the catch.

The FiB index (Pauly *et al.,* 2000) was computed from:

$$FiB = log\left[\left(\sum_i Y_{ik} \cdot 10^{TL_i}\right) \Big/ \left(\sum_i Y_{i0} \cdot 10^{TL_i}\right)\right] \tag{3}$$

where i and k are defined above, and where the subscript '0' refers to the year at the start of a series, which serves as anchor. The FiB index changes its value only when a decrease in TL is not matched by a corresponding increase in catch, and conversely for increasing TL. Here, 'corresponding' is defined as a 10-fold increase for a decline of one trophic level, as implied by a 10% transfer rate between trophic levels (Pauly and Christensen, 1995).

Finally, a piscivory index, the ratio of the sum of catches of piscivorous fishes (P) to the sum of catches of piscivorous (P) plus planktivorous fish, was computed. Here, the planktivores are identified by the letter Z (for zooplankton, although phytoplankton is also consumed, notably by the southern African sardine), to match the nomenclature of Caddy and GaribaldI (2000), who proposed this index. The text above gives our P, Z assignments, which are based on the diet information data also used to estimate TL values. The species consuming finfish or pelagic cephalopods were regarded as 'piscivorous,' while the rest were defined as '(zoo-) planktivorous' (which excluded detritivores and benthic-feeding fish that eat invertebrates off the sea bottom, and all invertebrates from this analysis). More precisely, the index in question was computed for each year from 1950 to 2000, using

$$Piscivory\ index = \sum_{j=1}^{n} P_k \Bigg/ \left(\sum_{j=1}^{n} P_k + \sum_{j=1}^{n} Z_k \right) \tag{4}$$

where P_k represents the reported catch of piscivorous finfish in year k and correspondingly for Z_k.

RESULTS AND DISCUSSION

Based on the analyses of total landings from 1950 to 2000 (Figure 1) and of the time series of indices of ecosystem status (Figures 2-5), three periods with distinct trends can be readily identified:

- the 'undeveloped' stage of the fishery (1950-64), when sardine dominated the catches in landed weight, and during which large fisheries, particularly for horse mackerel, Cape hake and chub mackerel developed;
- the 'developing/mature' stages of the fishery (1965-69), when landings and mean trophic level increased rapidly, followed by the collapse of the sardine stock; and
- the 'senescent' stage (1970-2000), during which the mean TL of catches stagnated (Figure 2), while the Piscivory index (Figure 3) and the FiB index (Figure 5) declined.

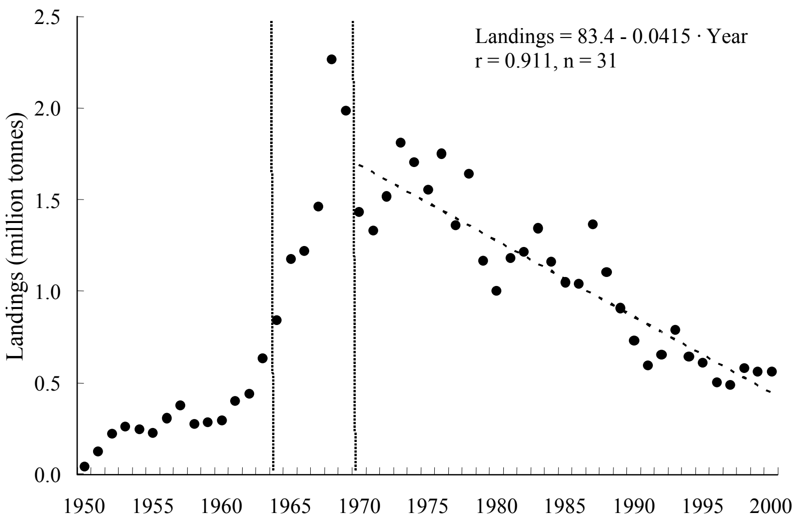

Figure 1. Analysis of catch time series from Namibian waters, 1950 to 2000, by major species groups. Note occurrence of three distinct periods, discussed in the text.

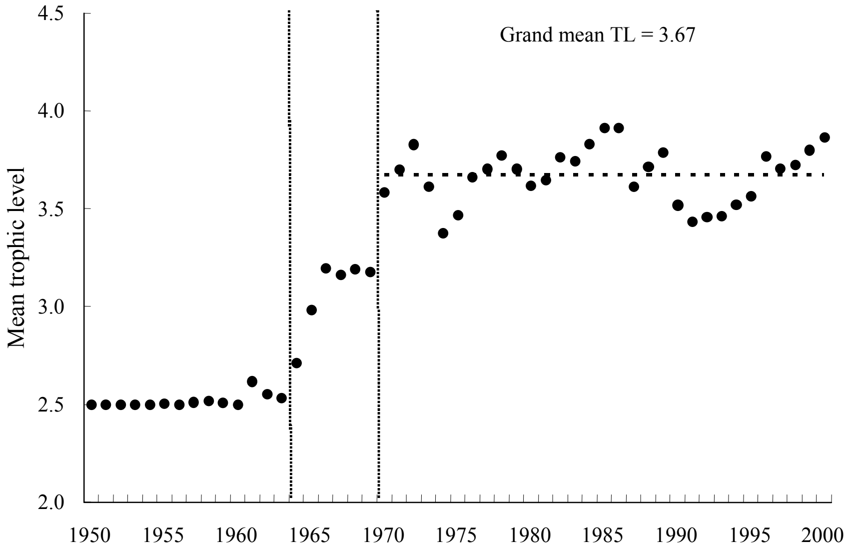

Figure 2. Time series of mean trophic level of catches from Namibian waters, 1950 to 2000. Note occurrence of three distinct periods, during the last of which stagnating mean trophic levels mask ecosystem changes detected by two other ecosystem status indices (see text).

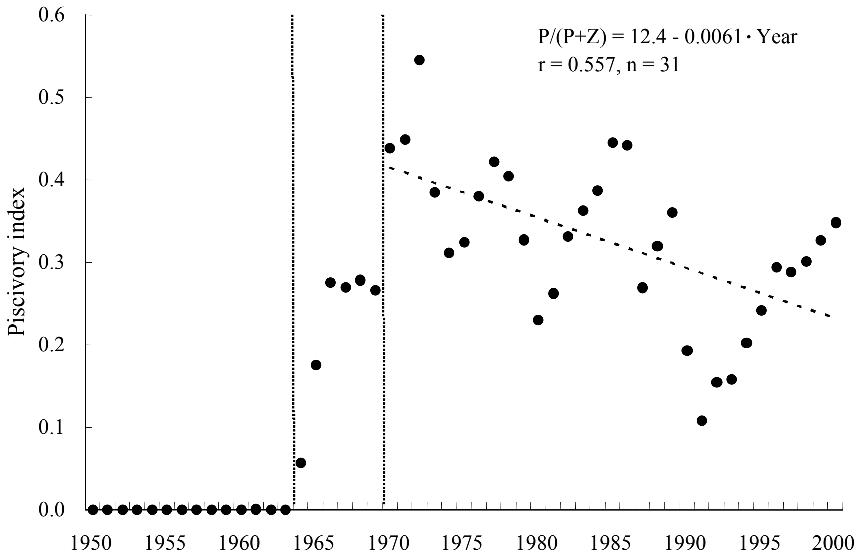

Figure 3: Time series of the ratio of piscivorous to zooplanktivorous fishes in catches from Namibian waters, 1950 to 2000. Note occurrence of three distinct periods, as in Figure 1.

In 1950-64, southern African sardine dominated the fishery with peak catches of 1.4 million tonnes in 1968, followed by a collapse in the early 1970s. During this period, the landings showed an increasing trend (Figure 1), while the mean TL (Figure 2) and the piscivory index showed no distinct trends (Figure 3), and the FiB index showed an increasing trend (Figure 5). Fisheries for Cape hake, horse mackerel and chub mackerel commenced in 1964, 1955 and 1971 respectively. Cape hake and horse mackerel landings peaked during the early to late 1970s. The second period, 1965-69, saw an increase in the impact of distant water fleets (DWF), which began operating off Namibia in the early 1960s (Bonfil, 1998). During this 5-year period, the rapid increases in landings (Figure 1), notably on shallow- and deep-water Cape hake, Cape anchovy, horse mackerel and rock lobster, were reflected as increases of all three ecosystem status indices.

These trends turned around during the 1970-2000 period, where declining trends are observed for total landings (Figure 1), piscivory index (Figure 3), and FiB index. Of these only the piscivory index indicates that fishing has impacted the ecosystem structure (the declining trend in the FiB index is trivial, as it reflects only declining catches). Here, contrary to our earlier analyses, which were based on preliminary estimates of trophic levels (Willemse, 2002; Willemse and Pauly, 2004), the impact of fisheries on the ecosystem is not reflected in the mean TL of catches, which stagnates during the period in question. We attribute this to the fact that off Namibia there is no

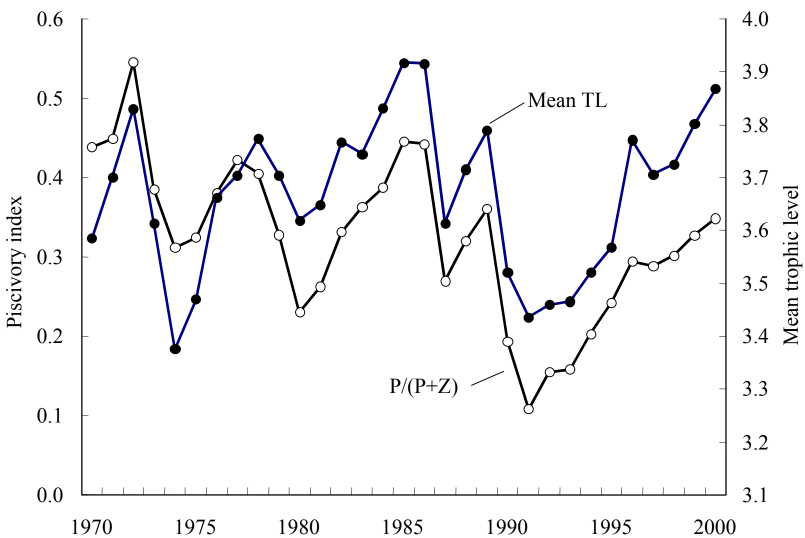

Figure 4: Mean trophic levels and piscivory index of fisheries catches from Namibian waters, 1970 to 2000. Note that the fluctuations of these two indices of ecosystem states in response to long-term environmental events are largely in phase, suggesting that they both reflect the same underlying phenomena (see text).

directed fishery for pelagic goby and other low level organisms (incl. jellyfish), which are now extremely abundant in the ecosystem. We are here reminded that for the 'fishing down marine food web' phenomenon to be detected, the assumption must be met that the relations between species in the fisheries catches used for the analysis broadly reflect their relative abundances in the ecosystem (Pauly *et al.*, 1998b).

The choice of trophic levels is also important: the use of different values in Willemse (2002) and Willemse and Pauly (2004), notably of a high value for southern African sardine (3.4 instead of the 2.5 value used here) generated for the 1970-2000 period what may have been a spurious downward trend of mean TL, not recorded here (see Figure 2).

Environmental fluctuations do matter in an ecosystem such as that occurring in Namibian waters, but they cannot be evoked to explain the 30 year trend in Figure 1, 2, and 5. Indeed, as might be seen from Figure 4, these fluctuations, while inducing the two ecosystem state indices in Figure 4 to vary in unison, do not prevent a long-term trend from appearing that can be readily explained by the gradual removal of large, piscivorous, high-TL species with benthic affinities, and their replacement, in the ecosystems and the catches, by predominantly planktivorous, small, low-TL species.

Thus, we can conclude that the fisheries off Namibia have induced changes of ecosystem structure mainly as a result of pre-independence overfishing. This implies increased management effort by the national govern-

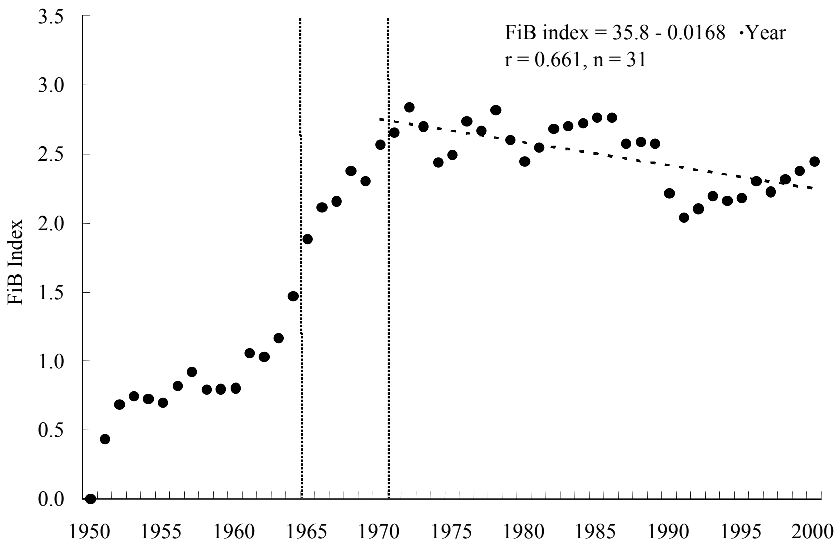

Figure 5. Time series of the FiB (fishing-in-balance) index for Namibian waters, 1950-2000. This series fails here to indicate anything beyond what a perusal of the catch trends (Figure 1) would suggest, owing to the catches, in this case, not reflecting changes in underlying ecosystem structure (see text).

ment. Also the research needs to be continued which has so far contributed to a much increased understanding of the Benguela ecosystem (Iyambo, 2001). However, this will require more emphasis on ecosystem-based indicators such as illustrated here.

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