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Sustainability implications of honouring the Code of Conduct for Responsible Fisheries

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ABSTRACT

The Code of Conduct for Responsible Fisheries developed in 1995 by the Food and Agriculture Organization (FAO) of the United Nations includes a set of recommendations for reducing the negative impacts of fishing activities on marine ecosystems. The Code is widely believed to be an important tool for fisheries management and, although the Code is voluntary, all stakeholders concerned with the management and development of fisheries, and conservation of fishery resources, are actively encouraged to implement it. Previous analysis at global scale showed widespread low compliance with the Code of Conduct that may be partly due to a lack of empirical support for the overall ecological benefits of adhering to the Code. Here we evaluated these ecological effects by comparing compliance with the Code to changes in five ecological indicators that quantify the ecosystem effects of fishing. We used the loss in production index and the related probability of sustainable fishing index, the mean trophic level of the catch, total catches, and the primary production required to sustain the catch. We also tested if regional differences and development status of countries influenced the results of ecological indicators. Results indicate that countries with higher levels of compliance with the FAO Code of Conduct in 2008 experienced a decrease in the Loss in Production index and an increase in fisheries sustainability from the 1990s to 2000s. We conclude that better implementation of the Code of Conduct may have had overall positive ecological effects with time. A significant decrease in total catch and primary production required with higher compliance was also observed. While a significant increase in ecosystem sustainability was observed after a decade of adoption of the Code at high levels of compliance, further ecosystem degradation had taken place where compliance with the Code was below a given threshold (4, from a ranking of 0–10). Therefore, since compliance with the Code is still low or very low worldwide, these results may encourage individual countries to adopt well-established fishery management measures in order to increase the ecological sustainability of marine resources.

1. Introduction

Despite reports of optimism in a few developed countries (Worm et al., 2009), worldwide most marine fisheries and exploited ecosystems are in a worrisome situation (e.g. Pauly et al., 2002, 2003; Christensen et al., 2004; Coll et al., 2008; Froese and Proelß, 2010). Therefore, several national and international initiatives have been issued with the aim to halt degradation trends and ensure the sustainability of fisheries, such as the European Community EC 2371/2002 (European Community, 2002), Canada's Oceans Act (Department of Justice Canada, 1996), and U.S. Commission on Ocean Policy (US Commission on Ocean Policy, 2004). These initiatives have been developed on the principles and standards adopted at global scale by the Food and Agriculture Organization of the United Nations (FAO) through the Code of Conduct for Responsible Fisheries (FAO, 1995).

The FAO Code of Conduct for Responsible Fisheries (termed "the Code of Conduct" in this study, see full text at http://www.fao.org/docrep/005/v9878e/v9878e00.HTM) was developed in 1995 and provides a detailed consensus for the sustainable, responsible and equitable exploitation of fishery resources. The Code, which was established under a wide scientific and policy consensus (Edeson, 1996), sets out clear ethical and scientific principles and standards applicable to the conservation, management and development of all fisheries with the explicit aim of ensuring the sustainable and equitable exploitation of aquatic living resources. The Code includes principles on fisheries management, fishing operations,

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aquaculture development, integration of fisheries into coastal area management, post-harvest practices and trade, and fisheries research targets (FAO, 1995). Our analysis, however, is focussed on compliance with Article 7 of the Code, which provides a comprehensive coverage of fisheries management issues and (a) includes the framework for management that should target long term objectives and consider the fish stocks as units for management, (b) advices for data gathering and consideration of available scientific information; (c) suggests the adoption of precautionary approach, (d) highlights measures for authorize, monitor and control fishing operations, and includes attention for indigenous and traditional practices, reduction of wastes and discards; and (e) considers a series of measures to facilitate effective implementation of regulation and laws. Being global in scope, Article 7 of the Code is directed towards all stakeholders concerned with the management, development and conservation of fishery resources. As it is the case for many international agreements addressing environmental global issues, the Code of Conduct is voluntarily implemented by countries and, under Article 3, FAO is committed to assisting countries in its efficient implementation, and reports to the UN community on the progress achieved and further action required (FAO, 1995).

Thirteen years after the publication of the Code of Conduct, Pitcher et al. (2009a,b, see http://awsassets.panda.org/downloads/un_code.pdf) compared the overall compliance of 64 jurisdictions (53 countries and other subsidiarity jurisdictions responsible for fisheries management and contributing 96% of the global marine catch) with the Code. The compliance was evaluated in 2008 using published and unpublished literature, and expert opinion questionnaires about fisheries management issues, largely collated in Pitcher et al. (2006). Incorporating conservation and socio-economic needs, formalization and scientific application of management targets, the adoption of the precautionary approach as well as the effectiveness of management, Pitcher et al. (2009a,b) defined indicators of both intention and actual performance in complying with the Code for each country. After constrained non-parametric multidimensional scaling analysis in six evaluation fields comprising 43 key features of Article 7 of the Code (Pitcher, 1999), the study allowed the ranking of countries in terms of compliance with the Code of Conduct. On a scale of compliance from 0 to 10, Pitcher et al. (2009a,b) found that no country achieved a good compliance score, and that compliance was overall low and positively correlated with indicators of wealth, transparency, quality of governance and general environmental performance of the country.

These results suggested that the implementation of the Code was mainly constrained by socio-economic drivers. Furthermore, the fields where most countries performed poorly were those that are critical to the sustainability of fisheries, such as the ecosystem-based management, the control of illegal fishing, reduction of excess fishing capacity and minimization of by-catch and destructive fishing practices (Pitcher et al., 2009a).

In our study, we argue that the lack of quantification of long-term ecological benefits of adoption of the code might have contributed to impair its implementation by countries. In fact, the assessments between compliance to international agreements addressing global environmental issues and actual results of following those agreements are essential to provide member states and key stakeholders with evidence on and confidence in the ecological efficacy of following these agreements. Since the adoption of fishery management measures implies costs for the country, it is important to know if the measures advocated in the Code to benefit exploitation of marine resources will likely have the expected ecological result.

Therefore, here we investigated the ecological consequences of implementing the Code by exploring the statistical relationship between degree of compliance with the Code of Conduct measured by Pitcher et al. (2009a,b) and changes in the sustainability of fishing activities at a national level after 1995. We hypothesized that higher levels of compliance with the Code of Conduct by country would have resulted in an increase of the sustainability of exploitation at an ecosystem level, while lower compliance would have produced a decrease in the sustainability.

However, changes in sustainability of fishing after 1995 might be related not only to Code compliance, but also to the ecological conditions before 1995, and the rate of development and expansion of fishing after 1995 that are depending on specific socio-economic traits of the country. Therefore we investigated our results globally and by continent, enabling us to reduce socioeconomic and ecological differences between countries and take into account large differences in historical fishing development. Moreover, developing and developed countries may show differences in how Code compliance relates to ecological status, and so we included this factor in our analysis.

We examined how compliance with the Code of Conduct related to five ecological indicators widely used to assess impact of fishing activities: (i) an index of ecosystem overfishing (the Loss in Production index, or L index); and (ii) the probability of the ecosystem being sustainably fished (P_{sust}) (Coll et al., 2008; Libralato et al., 2008; Mora et al., 2009); (iii) the mean trophic level of the catch (TLc, Pauly et al., 1998; Pauly and Palomares, 2005; Pauly and Watson, 2005); (iv) the total amount of catch (Y); and (v) total catches expressed as units of primary production required from the ecosystem to yield that catch (%PPR, Pauly and Christensen, 1995; Swartz et al., 2011). Although other factors could be considered, we restricted our analysis to explore relationships between these ecological indicators and compliance with the Code of Conduct (Article 7) on the hypotheses that (a) compliance is by definition an overall synthetic measure of many policies, (b) adoption of the Code has a primary influence on ecosystem effects of fishing, and (c) the above reported ecological indicators are synthetic measures of impacts of fisheries on ecosystems. Therefore the relationship between degree of compliance with the code and indicators' change after Code adoption by country is providing evidence of the ecological benefits of adopting policies in agreement with the Code of Conduct.

Specifically, we quantified (i) the relationship between changes on these ecological indicators from 1990s to the 2000s and the degree of adoption of the FAO Code of Conduct a decade earlier (compliance), and we then (ii) used our findings to derive a Code adoption efficiency threshold: the minimum compliance with the Code of Conduct necessary to improve the overall ecological status of an exploited ecosystem and to avoid further degradation due to fishing.

2. Materials and methods

2.1. Measures used to assess the sustainability implications of adopting the Code of Conduct

Compliance with the Code of Conduct for Responsible Fisheries (Pitcher et al., 2009a,b) and the five ecological indicators that we have compared with compliance to the Code were previously largely documented and applied to study the impact of fishing on marine ecosystems (e.g. Pauly and Christensen, 1995; Pauly et al., 1998; Cury et al., 2005; Pauly and Palomares, 2005; Pauly and Watson, 2005; Tudela et al., 2005; Coll et al., 2008; Libralato et al., 2008; Mora et al., 2009; Swartz et al., 2011). Below we provide some details on how the compliance with the code of Conduct and the additional ecological indicators were calculated.

2.1.1. Compliance with the Code of Conduct for Responsible Fisheries

On the basis of several measures adopted and implemented at country level for reducing impacts of fishing, a measure of compliance with the Code of Conduct for Responsible Fisheries by the Food and Agriculture Organization of the United Nations was defined by Pitcher et al. (2009a,b). Focusing on Article 7 of the Code of Conduct (regarding Fisheries Management; FAO, 1995) and using a questionnaire developed from the Code (Pitcher, 1999), Pitcher et al. (2009a,b) assessed for each country the 6 main evaluation fields, i.e. (i) management objectives, (ii) management framework and procedures, (iii) data gathering and management advice, (iv) precautionary approach, (v) management measures, and (vi) implementation. The questions were scored on the basis of cited published and unpublished literature and on the basis of cross-validated expert opinion with a protocol using a form of the Delphi technique (Linstone and Turoff, 2002). The performance of each nation was ranked using a non-parametric multidimensional scaling of standardized scores with fixed anchors representing "good" and "bad" situations (Pitcher et al., 2009a,b). Scored compliance with the Code of Conduct ranks from 0 (no compliance) to 10 (perfect compliance), thus a score of 5 represents compliance of 50% of the evaluated traits. When determining the scores, compliance scoring team members were asked to bear in mind a threshold of 4/10 as a "pass" score and 7/10 as a "good" score: all scores were hedged with uncertainty limits. However, a particular compliance score can be obtained through different combinations of scores in the evaluation fields (see Pitcher et al., 2009b for more details). Here, we used the scores of the overall compliance with the Code for 53 countries and other subsidiarity jurisdictions responsible for fisheries management (total of 64 areas) that landed over 96% of the global marine catch (Pitcher et al., 2009a) (Fig. 1 and Annex 1 in Supplementary Material).

2.1.2. Mean trophic level of the catch, total catch and primary production required

The trophic level (TL), originally defined as an integer value identifying the position of organisms within a food chain (Lindeman, 1942), was later modified into a fractional value accounting also for omnivory and the complex set of links in food webs (Odum and Heald, 1975). Following an established convention that TL = 1 for primary producers and detritus, the TL for consumers can be calculated as follows:

$$\mathrm{TL}_j = 1 + \sum_{i=1}^{n} \mathrm{DC}_{ji}\mathrm{TL}_i \quad (1)$$

where j is the predator of prey i, DC_{ji} is the fraction of prey i in the diet of predator j and TL_i is the trophic level of prey i.

The mean trophic level of the catch (TLc) represents a synthetic measure of where in the food web are the targets of fisheries and reflects the fishing strategy. Ecosystem effects of fishing influence the average TL of the fish community and thus TLc is also expected to decline as fishing impacts increase, according to the fishing down food-web effect (Pauly et al., 1998; Pauly and Palomares, 2005; Pauly and Watson, 2005; Swartz et al., 2011). TLc is calculated as the weighted average TL of harvested species (Pauly et al., 1998):

$$\mathrm{TLc} = \sum_i \mathrm{TL}_i \cdot (Y_i / \sum_i Y_i) \quad (2)$$

where Y_i are the catches of species (i).

The primary production required (PPR) to sustain the catch, typically measured as tC km^{-2} year^{-1} (C = carbon units), is obtained by back-calculating the flows needed to sustain the total catch (Y) for all pathways from the exploited species down to the primary producers and detritus and it is expressed in primary production and detritus equivalents:

$$\mathrm{PPR} = \frac{1}{9} \cdot \sum_i \left[Y_i \cdot \left(\frac{1}{\mathrm{TE}}\right)^{\mathrm{TL}_i - 1} \right] \quad (3)$$

where Y_i is the catch of a given group (i), TE is the mean transfer efficiency, TL_i is the trophic level of a group (i) and factor 1/9 is taken as the average conversion coefficient from wet weight to gC (Pauly and Christensen, 1995). PPR index can be expressed per unit of primary production and detritus of the ecosystem thus obtaining relative PPR (%PPR). %PPR allows comparison of catches with very different species composition from different ecosystems, and has been used as a measure of the footprint of fishing, i.e. higher %PPR is related with higher level of exploitations and fishing pressure (Pauly and Christensen, 1995; Swartz et al., 2011).

2.1.3. Loss in production and the probability of the ecosystem being sustainably fished

The Loss in Production index (L index) is based on the notion that catches represent a net export of mass and energy that can no longer be used within the exploited ecosystem and that the more production is being lost (taking into consideration ecosystem and fishing features), the more vulnerable the ecosystem becomes to fishing (Libralato et al., 2008). The index takes into account both properties of the ecosystem (the primary production, PP, and

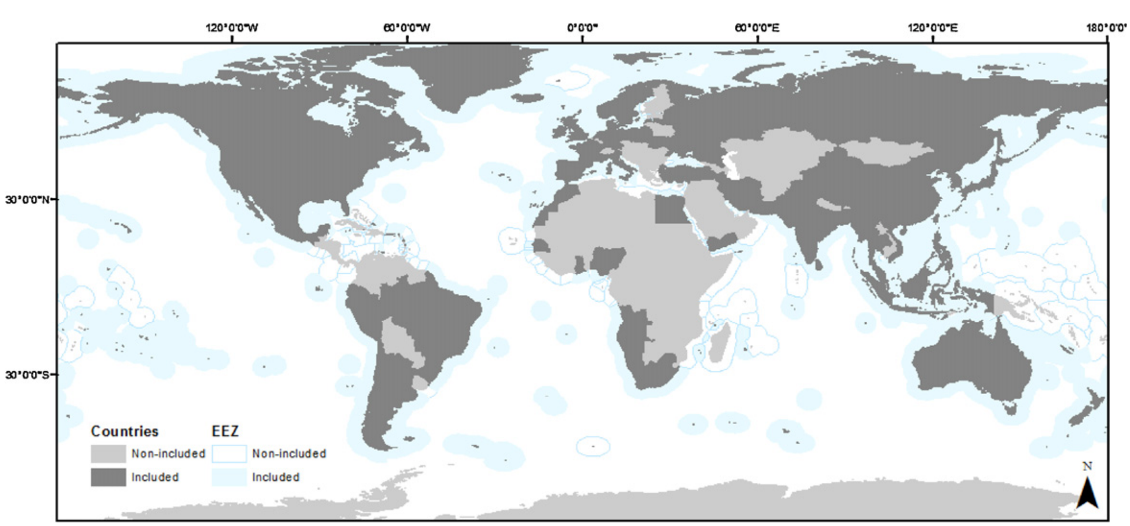

Fig. 1. Map indicating those countries and other subsidiarity jurisdictions responsible for fisheries management included in the analysis and their economic exclusive zones.

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transfer efficiency, TE) and characteristics of fishing activity (mean trophic level of the catch, TLc, and the primary production required to yield the catch, PPR, Lindeman, 1942; Pauly and Christensen, 1995; Pauly et al., 1998), thus it integrates the following ecological indicators:

$$L \cong -\frac{\mathrm{PPR} \cdot \mathrm{TE}^{m\mathrm{TLc}-1}}{\mathrm{PP} \cdot \ln \mathrm{TE}} \quad (4)$$

Since L quantifies the theoretical depletion of ecosystem secondary production due to fishing and it increases with fishing pressure, this index was proposed as a proxy to characterize the effects of fishing on the ecosystem, and was related to a measure of the probability that the ecosystem is being sustainably fished (P_{sust}) (Libralato et al., 2008). In particular, L index was calculated using outputs from a set of 51 well documented models of exploited ecosystems distributed worldwide and classified as representing an (1) overfished or (2) sustainably fished ecosystem based on the ecosystem overfishing definition *sensu* (Murawski, 2000). Then, for any theoretical value of the L index (L^*), the probability to be sustainably fished P_{sust} is calculated on the basis of the number of models of overexploited ecosystems with $L < L^*$, i.e. $P(L_1 < L^*)$, and the number of models representing sustainably fished ecosystem with $L > L^*$, i.e. $P(L_2 > L^*)$ as:

$$P_{\mathrm{sust}}(L^*) = \frac{P(L_2 > L^*)}{P(L_2 > L^*) + P(L_1 < L^*)} \quad (5)$$

thus allowing to obtain an empirical relationship between L index and P_{sust} (Libralato et al., 2008). Although a derived measure, P_{sust} has the advantage of representing in an intuitive probability scale the sustainability of fisheries in the ecosystem (0 = no probability for the system of being sustainably fished; 1 = 100% probability of the system of being sustainably fished). Moreover, the relationship between L and P_{sust} is useful for estimating reference values for the L index: by fixing any desired reference for sustainability of the fisheries, $P_{\mathrm{sust}} = p$ (e.g. 75%), the empirical relationship permits to calculate the correspondent reference values of the index $L = L_{\mathrm{p}}$. Limitations of the L index and P_{sust} have been discussed in detail elsewhere (Libralato et al., 2008).

By definition L index is expected to increase and P_{sust} is expected to decrease as fishing pressure increases. Both L index and P_{sust} have been used to evaluate ecosystem overfishing at a global scale (Coll et al., 2008), and to relate the effectiveness of fishing management to fishing sustainability (Mora et al., 2009).

Given that L index and P_{sust} are built to comprehensively summarize effects of fishing on TLc, Y and %PPR, and given that P_{sust} is complementary to L index and provides a synthetic reference for ecosystem sustainability, in the second part of our analysis we focussed on evaluating P_{sust} changes over time in relation to the degree of adoption of the Code of Conduct to estimate the Code adoption efficiency threshold.

2.2. Data sources

We calculated the ecological indicators by country and year from 1990 to 2003 using disaggregated catch data (Y) by each country Exclusive Economic Zone (EEZ) and primary production estimates (from the Sea Around Us project Global Fisheries Mapping data, version 4.0, http://www.searoundus.org, Pauly, 2007). Catch data by country was corrected by assuming different percentages of Illegal, Unregulated or Unreported catches based on Agnew and colleagues (2009), updating those values of L index and P_{sust} used in Mora and colleagues (2009). The Sea Around Us project Global Fisheries data also provided the TLi from which we calculate the TLc. Values of TE were obtained from data available by ecosystem type previously calculated from ecosystem models (Libralato et al., 2008). The %PPR was calculated by year and country using TLc, TE, Y and PP from this database. PP estimates were derived from SeaWiFS's global ocean colour satellite data and for 1998. These data allowed us to calculate the mean and standard error of L index, P_{sust}, TLi, Y and %PPR for the period 1990–1999 (henceforth called "1990s") and for 2000–2003 (named period "2000s"). Given that the Code of Conduct was introduced in 1995 and was gradually applied, the above reported periods are considered to be representative of the period before and after the introduction and eventual application of the Code of Conduct, respectively, and thus were used to test the ecological effects of the Code's application.

2.3. Comparison of indicators

Compliance with the Code of Conduct and average values of L index, P_{sust}, Y, %PPR and TLc were compared by country, continent, by development status of the country, and by time-period. We compared changes observed in the values of the indicators during 1990s in comparison with 2000s in relation with the values of compliance with the Code of Conduct evaluated in 2008.

We used a distance-based multiple linear model (DISTLM) based on permutational methods and Euclidean distances to examine differences in individual indicators L index, P_{sust}, Y, %PPR and TLc (considered as dependent or response variables, y) as a function of the compliance to the Code of Conduct scores (considered as independent or predictor variable, x) (using the PERMANOVA module in PRIMER with PERMANOVA+ v. 6, PRIMER-E Ltd., Plymouth, UK, Legendre and Anderson, 1999; Anderson et al., 2008). DISTLM is a routine to analyze, model and predict the relationship between multivariate data described by a resemblance matrix of response variables, and one or more predictor variables. DISTLM allows for the analysis of complex designs (multiple independent and dependent variables, including categorical variables) without the constraints of multivariate normality and homoscedasticity. The method calculates a pseudo-F statistic directly analogous to the traditional F-statistic for ANOVA models but uses permutation procedures to obtain p-values for each term in the model (Anderson et al., 2008).

In addition to the compliance to the Code, we assessed the potential contribution of other predictor variables to the change on ecological indicators from 1990s to 2000s: (i) the continent where countries were located (North America, South America, Europe, Africa, Asia and Oceania) included as a categorical variable in the analysis, and (ii) the development status of the country measured with the Human Development index (HDI) scores (UNDP, http://hdr.undp.org). These variables enabled us to consider geographic and socioeconomic differences between countries as factors explaining the changes observed for each indicator. We conducted marginal tests (for analysing the relationship between a dependent variable and an individual independent variable) and conditional or partial tests (for analysing such relationship after fitting one or more other variables).

Before the analysis, we first assessed skewness of the ecological indicators with a draftsman plot (matrix of plots of each indicator against the other). Properties were not skewed, thus no transformation was necessary, but they were all normalized prior to the analysis. Linear regressions were evaluated by performing assessments on residuals and on the leverage of each data in determining results (performed in R, see Annex 2 in Supplementary Material).

Finally, we used linear regressions between the compliance with the Code of Conduct and P_{sust} to extrapolate the minimum Code compliance level that may be translated into an improvement in ecological sustainability. Given the linear relationship $y = ax + b$,

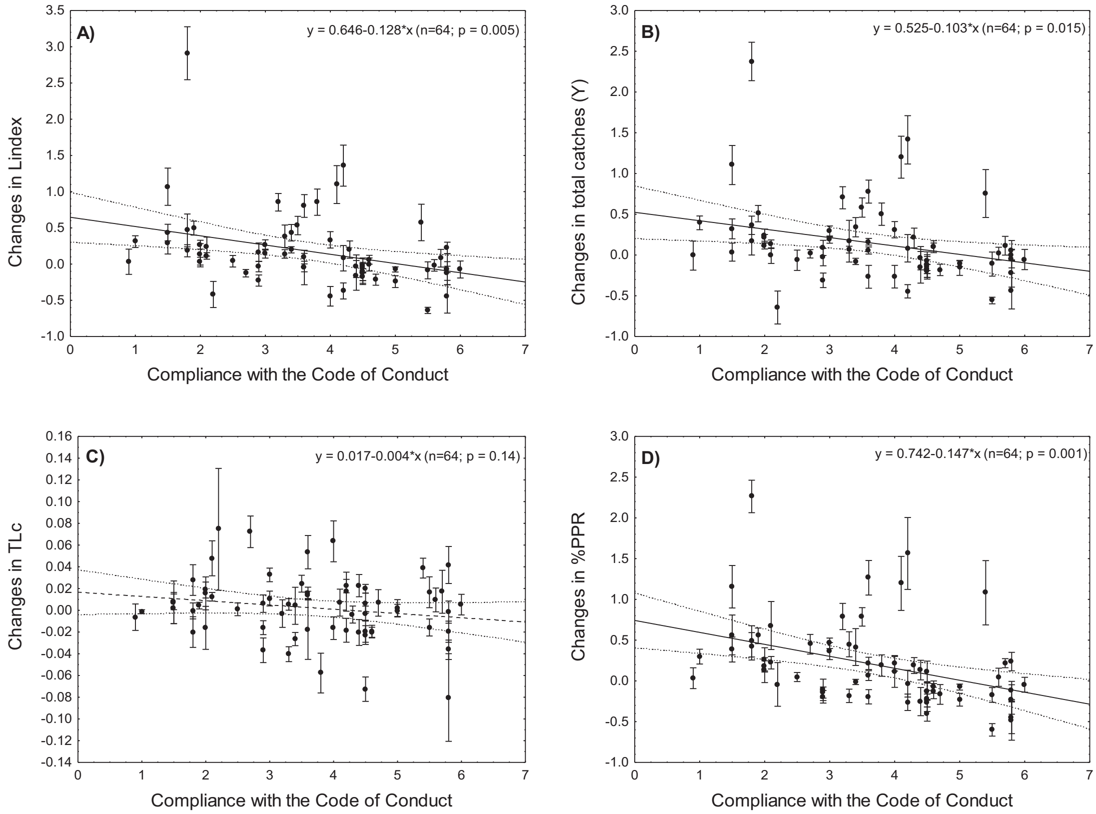

Fig. 2. Relationships between changes in (a) *L* index, (b) total catch (*Y*), (c) mean trophic level of the catch (TLc), and (d) primary production required to sustain the catch (%PPR) from 1990s to 2000s, and the compliance with the Code of Conduct for Responsible Fisheries by the Food and Agriculture Organization of the United Nations. Linear regression analysis results are shown in Table 1, and the linear trend of the regressions is indicated by a solid line if regression is significant at the 0.05 level.

the ratio $-b/a$ provided an estimate of such threshold, and the error was estimated from propagation of SE of parameters *a* and *b*.

Data used in our analysis are provided in Annex 3 in Supplementary Material.

3. Results

3.1. Changes in ecological indicators and the compliance with the Code of Conduct

Comparing compliance scores of the Code of Conduct with relative changes in the ecological indicators from 1990s to 2000s showed significant (i.e. $p \leq 0.05$) negative relationships between *Y*, %PPR and *L* index with the compliance scores (Fig. 2). These relationships illustrate that higher values of the Code of Conduct in 2008 corresponded to significant decreases in total catch and the primary production required to sustain those catches by country, and to significant decreases of the total loss in secondary production from the ecosystem from 1990s to 2000s (Table 1). The relationship between TLc and compliance was not statistically significant (Fig. 2c and Table 1).

The additional factor included in our analysis regarding the location of the countries by continent did not influence our results and did not explain data variability, except for the regression analysis of the TLc (Table 1). On the contrary, the Human Development Index showed significant relationships with P_{sust}, *L* index, *Y* and %PPR in marginal tests (i.e. all indicators except TLc, see Table 1) and with P_{sust}, *Y* and %PPR in sequential tests (all indicators except TLc and *L* index, see Table 1). These results illustrate that HDI was also correlated with changes in several ecological indicators, both included as a unique variable or after taking into account the impact of compliance.

In addition, the comparison of the compliance scores and sustainability P_{sust} values between the 1990s and the 2000s showed that those countries ranking higher in compliance also exhibited a significant increase in the sustainability of fisheries

Table 1
Linear relationships between changes (Δ) in the mean trophic level of the catch (TLc), total catch (*Y*), primary production required to sustain the catch (%PPR), and *L* index from 1990s to 2000s, and the compliance with the Code of Conduct. SE, standard error; *a* and *b* are the coefficients of the linear regression (Fig. 2). Contributions of other independent variables (continents and development) in the multiple linear regressions are also indicated. *p*-Values are computed with permutational methods using the distance-based multiple linear model (DISTLM) (marginal/partial test results are shown).

Indicators	Compliance with the Code			Continent	Development (HDI)
	$a \pm$ SE	$b \pm$ SE	*p*-Value	*p*-Value	*p*-Value
ΔP_{sust}	0.090 ± 0.038	−0.382 ± 0.148	**0.0186**	0.197/0.79	**0.006/0.004**
ΔL index	−0.128 ± 0.044	0.646 ± 0.173	**0.0039**	0.150/0.146	**0.004**/0.54
ΔTLc	−0.004 ± 0.003	0.017 ± 0.010	0.1379	**0.015/0.013**	0.087/0.430
ΔY	−0.103 ± 0.041	0.525 ± 0.162	**0.0121**	0.2255/0.611	**0.006/0.007**
Δ%PPR	−0.147 ± 0.043	0.742 ± 0.168	**0.0008**	0.1448/0.869	**0.0005/0.0003**

Bold *p*-values highlight significant results.

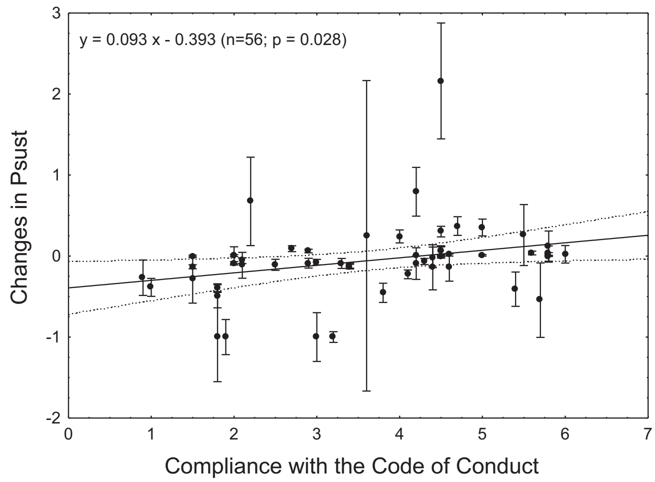

Fig. 3. Relative changes in the sustainability of fishing (P_{sust}) and compliance with the Code of Conduct calculated as the relative difference from the 1990s and the 2000s periods. The linear trend of the regression is indicated by a solid line since regression is significant at the 0.05 level.

with time (Fig. 3, and Table 2, first row). These results illustrate that better alignment with the Code of Conduct by country had overall positive ecological effects with time.

Results by compliance scores highlighted that countries with low compliance had a progressive decrease in P_{sust} values, whereas countries with high compliance showed stable or increasing values of P_{sust} (Fig. 4a and b). Since initial average values of P_{sust} (in 1990) were not significantly different among compliance categories (*t*-test was not significant for all possible combinations), our result is robust and does not depend on the initial average values of P_{sust} for the different compliance categories. Complementing the above, results obtained for the *L* index showed that countries with low compliance had a progressive increase in *L* index, whereas countries with high compliance had *L* values that were stable or decreasing (Fig. 5a and b). Results for both *L* index and P_{sust}, therefore, showed deteriorating ecosystem effects (decrease of P_{sust} and increase of *L* index) for low values of compliance with the Code of Conduct and improvement of sustainability (increase of P_{sust} and decrease of *L* index) for higher levels of adoption of the Code (Figs. 4 and 5).

3.2. Code adoption efficiency threshold

The empirical relationship between compliance with the Code of Conduct and changes in the Loss in Production index (*L* index) and fisheries sustainability (P_{sust}) allowed extrapolating the minimum Code compliance level that may be translated into an improvement in ecological sustainability (Fig. 3). The marginal effect in terms of P_{sust} for each unit of compliance was indicated by the regression slope ($a = 0.093$ for all data pooled together, first row Table 2; $a = 0.1026$ and $a = 0.0862$ for mean and medians of data categorized by compliance, respectively). This implied an approximate 10% increase in the sustainability of the fisheries in the period 1990–2003 per adopted unit of compliance with the Code (Fig. 3), equivalent to an increase in P_{sust} of approximately 1% per year per each further adopted unit of the compliance with the Code of Conduct.

In addition, the ecological consequence of zero compliance with the Code (compliance score = 0) is indicated by the intercept of the linear regression and implied an average decrease of sustainability of 36–42% in the same time span, potentially occurring in cases when none of the measures indicated by the Code of Conduct were adopted. Higher levels of compliance (≥compliance score of 4 out of 10) seemed to produce a significant improvement in fisheries sustainability, while values of compliance with the Code generally lower than a score of 4 may be translated into degradation (Table 3). These results suggest that compliance with the Code equal to level 4 may therefore be regarded as the minimum threshold level above which adoption of the Code of Conduct is effective in increasing the ecological sustainability of exploited ecosystems, whereas below this value fishing drives a worsening of ecosystem conditions.

3.3. Results by contrasting initial sustainability conditions

Our analysis also showed that changes in fisheries sustainability during 1990–2003 in relation to the Code compliance were marginally different for contrasting values of initial sustainability (Fig. 6 and Table 2). We observed a steeper positive slope of the linear relationship between P_{sust} and compliance for countries that had low sustainability in the 1990s (i.e. values of P_{sust} in the 1990s that were lower than 25%) (Fig. 6) than for those that started with intermediate and higher sustainability levels in the 1990s (i.e. values of $25\% < P_{sust} < 75\%$ and $P_{sust} > 75\%$, respectively) (Fig. 6 and Table 2). Regression reported in Fig. 6 showed slopes of 0.16, 0.074 and 0.0365, respectively for low, intermediate and high P_{sust} in the 1990s. Therefore, and following previous results about the threshold, low compliance with the Code (<4) was likely to worsen the sustainability of both under and over-exploited systems, but this effect was more severe in already depleted areas ($P_{sust} < 25\%$). Conversely, higher levels of compliance may produce relatively larger improvements in the sustainability of already depleted systems (i.e. when $P_{sust} < 25\%$), than in more sustainable situations (when $P_{sust} > 75\%$) where similar levels of compliance allow for maintaining healthier conditions. Minimum efficiency threshold increases as the initial sustainability increases (Table 2). Therefore, whereas a compliance with the Code at a level higher than 4 may suffice to increase sustainability of an exploited ecosystem that is at low sustainability levels, higher levels (compliance score > 5) may be necessary to see improvements in more sustainable conditions (Fig. 6, and Table 2 last rows).

4. Discussion

In this study we evaluated the ecological effects by country of adopting the Code of Conduct for Responsible Fisheries by the Food and Agriculture Organization of the United Nations (FAO, 1995) by

Table 2
Thresholds resulting from the empirical relationship between compliance with the Code of Conduct and changes (Δ) in fisheries sustainability P_{sust} from 1990s to 2000s (Fig. 6). SE, standard error; *a* and *b* are the coefficients of the linear regression. *p*-Values (bold, when significant) are computed with permutational methods using the distance-based multiple linear model (DISTLM).

ΔP_{sust}	$a \pm$ SE	$b \pm$ SE	Threshold ± SE	*p*-Value
All countries	0.093 ± 0.041	−0.393 ± 0.162	4.24 ± 0.09	**0.028**
Countries with $P_{sust} < 25\%$ in the 1990s	0.159 ± 0.10	−0.64 ± 0.42	4.00 ± 0.4	0.142
Countries with $25\% < P_{sust} < 75\%$ in the 1990s	0.074 ± 0.05	−0.32 ± 0.17	4.32 ± 0.11	0.123
Countries with $P_{sust} > 75\%$ in the 1990s	0.037 ± 0.018	−0.197 ± 0.075	5.40 ± 0.03	0.069

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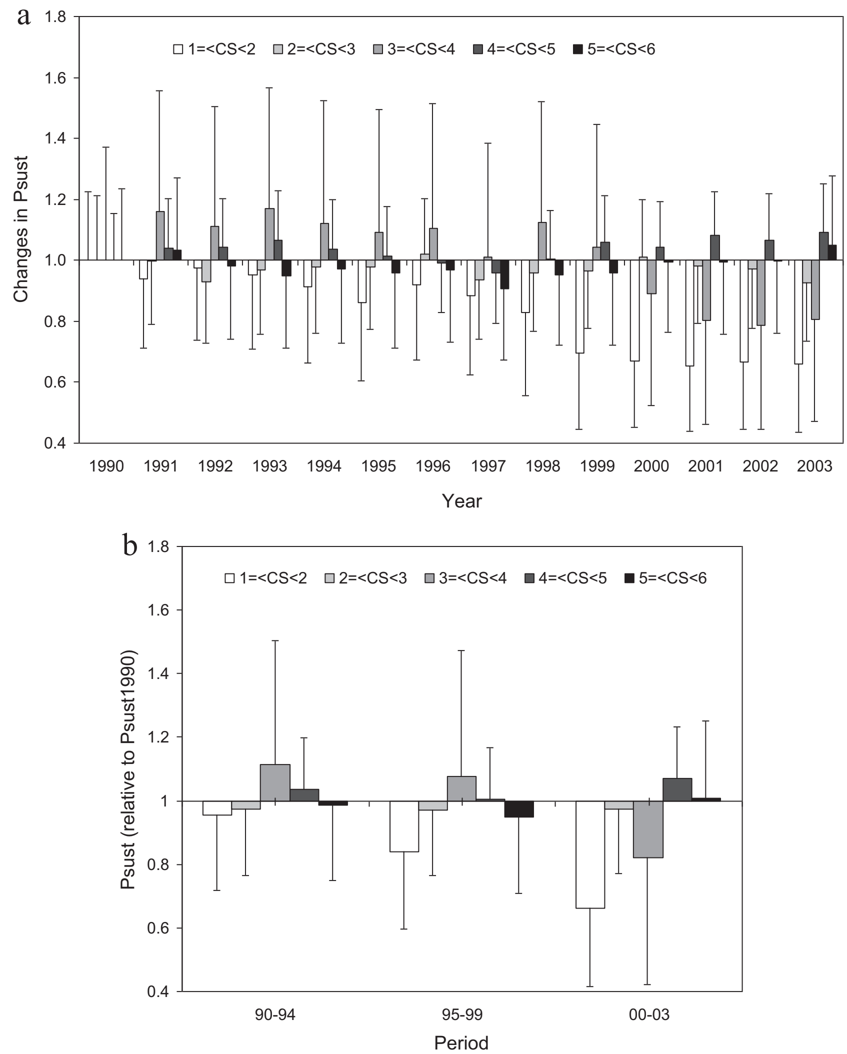

Fig. 4. Relative changes over time of P_{sust} for countries grouped by compliance score (CS): (a) year-by-year changes (upper panel), and (b) averages for three periods (1990–1994; 1995–1999; 2000–2003).

comparing levels of compliance with the Code with changes in indicators of the ecosystem effects of fishing. Such evaluations are needed to assess the efficacy of adopting international voluntary agreements and to quantify the ecological benefits of complying with international agreements addressing global environmental issues. These assessments are essential for providing member states and other key stakeholders with confidence in the agreements, while proved ecological improvements due to agreements adoption are useful trade-offs to be used for counterbalance costs of adoption.

In our study we compared the compliance with the Code evaluated in 2008 to changes in ecological indicators used to evaluate ecosystem effects of fishing from 1990s to 2000s. Our results show a clear relationship between the compliance with the Code of Conduct and all the ecological indicators investigated except the mean trophic level of the catch (TLc). Therefore, this study illustrates that countries with higher adherence to the Code of Conduct for Responsible Fisheries gained some clear ecological benefits a decade after the Code's establishment. For those countries with higher compliance with the Code of Conduct we found a clear significant increase in the sustainability of exploited ecosystems (P_{sust}), while total removals - either expresses as total catches, primary production required to sustain the fisheries, or as the loss of production due to fishing, significantly decreased from 1990s to 2000s. Results also highlighted that ecosystem degradation due to fishing and reported in many global evaluations (Pauly et al., 1998; Jackson et al., 2001) is done at a pace that minimum levels of adoption of the code (compliance < 4) are not sufficient to balance the negative ecological impacts of fishing.

Our hypothesis is that changes in these ecological indicators over time are due to different degree of adoption of the Code of Conduct as synthesized by the compliance indicator developed by Pitcher et al. (2009a). However, confounding factors can be claimed to intervene in the relationship we found between the ecological indicators and the Code of Conduct and thus alternative models can be considered. For instance, since compliance scores < 3 are dominated by African and Asian countries and high compliance are predominant of Europe and North America countries, the region effect might contribute to explain observed trends.

However, our results did not support the hypothesis that changes in the ecological status of marine exploited ecosystems in relation to the compliance with the Code of Conduct are dependent on regional differences. In fact, the analysis of trends by continent showed that the positive relationship between sustainability and compliance with the Code is consistent and not biased by inter-regional differences. On the contrary, we found a significant contribution of the Human Development Index in addition to the compliance to the Code, which may reflect that the stage of

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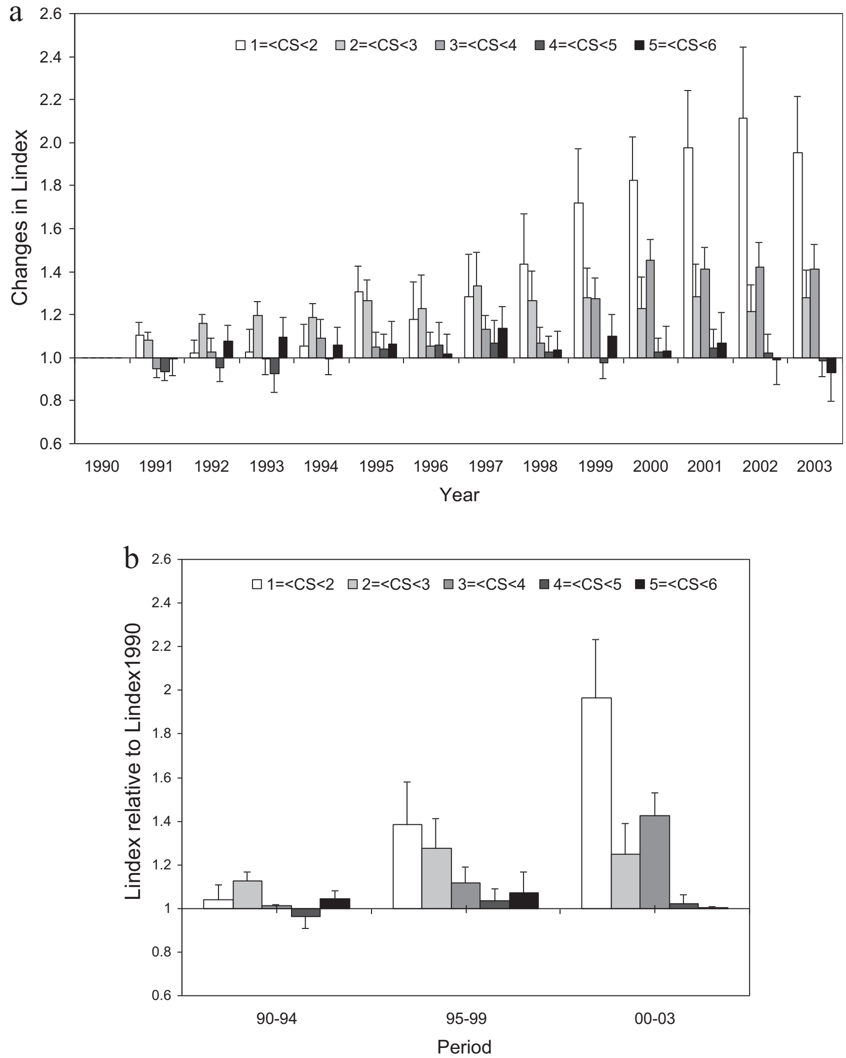

Fig. 5. Relative changes over time of L index for countries grouped by compliance score (CS): (a) year-by-year changes (upper panel), and (b) averages for three periods (1990–1994; 1995–1999; 2000–2003).

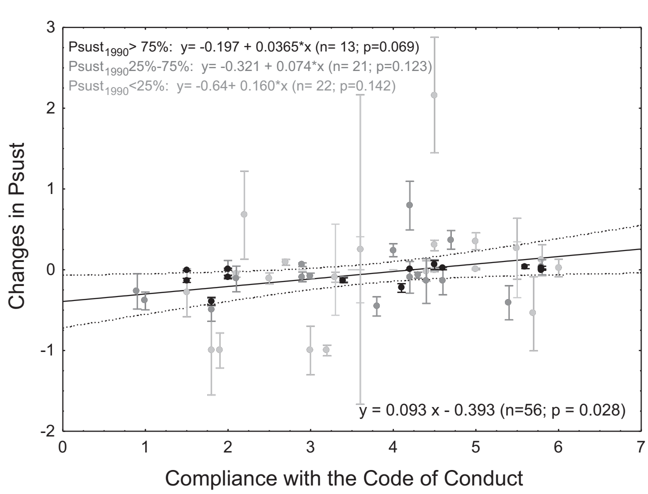

Fig. 6. Relative changes of sustainability of fishing, P_{sust}, by compliance for countries grouped by contrasting levels of initial P_{sust}, i.e. in the 1990s (initial $P_{sust} < 25\%$, initial P_{sust}: 25%-75% and initial $P_{sust} > 75\%$). The linear trend of the regressions is indicated by a solid line if regression is significant at the 0.05 level and linear regression analysis results are also shown in Table 2. Only the linear trend of the regressions for the whole set of data is indicated for the sake of clarity (solid line if regression is significant at the 0.05 level).

development of the country during our study period influenced both the initial sustainability of fishing and its change over time. The positive correlation between compliance and the HDI index (Pitcher et al., 2009a), and between the HDI and the increase of sustainability of fishing (Fig. 7a) does not allow to completely separate the effects on sustainability of country development and compliance to the Code of Conduct. For instance, high values of HDI and compliance both imply an increase in sustainability and relative effects are difficult to separate. Nevertheless, despite that the developmental stage of the country measured by HDI appears as an explanatory factor of improvement in sustainability, in all analyses (marginal and partial tests), the compliance with the Code of Conduct was highly significantly related. Moreover, the high significance of partial tests for compliance was independent of the order of factors (compliance, HDI and continent; results not shown). This supports our main hypothesis that improvements in sustainability of fishing are directly related with the degree of compliance to the Code of Conduct. Therefore, the positive relationship between the adherence to international agreements and ecological improvement of exploited marine ecosystems may hold worldwide. This result is important since it highlights possible trade-offs to be accounted, especially by those countries whose socio-economic features limit the available resources, to comply with the Code of Conduct (Pitcher et al., 2009a), in a

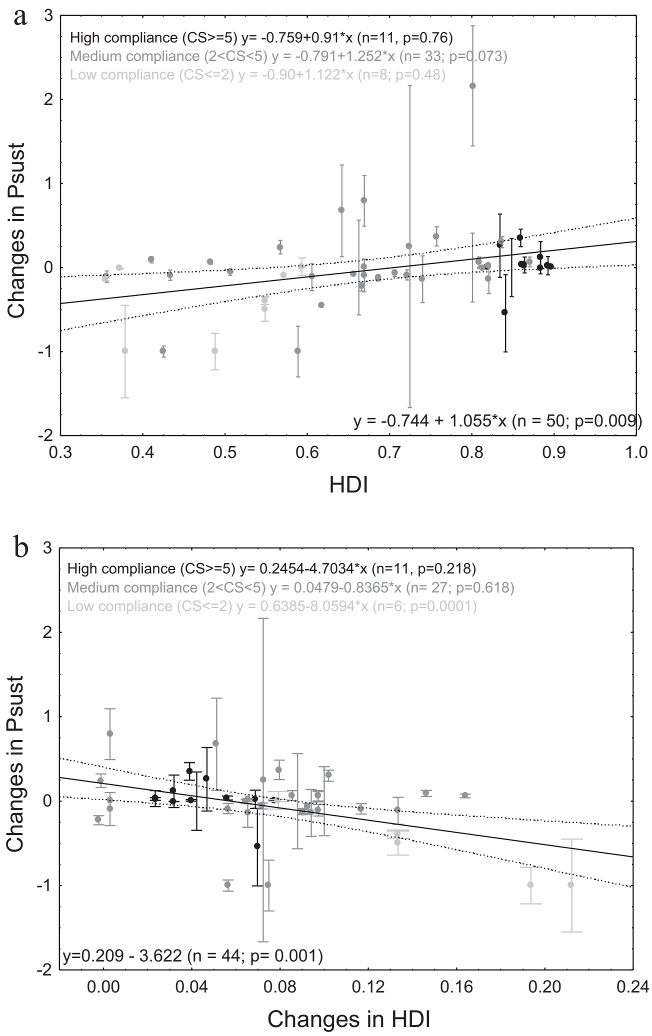

Fig. 7. Relative changes in the sustainability of fishing (P_{sust}) in relation with the Human Developmental Index (HDI) for countries grouped by contrasting levels of Compliance with the Code of Conduct (high compliance, CS > 5; medium compliance, 2 < CS < 5; low compliance, CS < 2). Data of P_{sust} change are represented against average values of HDI in panel (a) and against change in HDI over the same period of time in panel (b). Only the linear trend of the regressions for the whole set of data is indicated for the sake of clarity (solid line if regression is significant at the 0.05 level).

context where there is an expansion of fishing towards southern areas in developing countries (Coll et al., 2008; Swartz et al., 2011). To this regard we also found a negative relationship between the changes of sustainability of fisheries and changes in HDI index from the 1990s to 2000s for countries with high, intermediate and low compliance with the code (Fig. 7b) indicating that human development in our study areas may have been at the cost of environmental sustainability. However, the complexity of this issue requires further investigation.

In this study sustainability metrics are estimated on an EEZ basis and are assigned to the corresponding coastal State. It can be argued that this procedure could not allow disclosing which part of the footprint corresponds to fleets from developed states operating in EEZs overseas, under fishing agreements or other access formulas. However, catch data by country (from the Sea Around Us project Global Fisheries Mapping data, version 4.0, http://www.searoundus.org, Pauly, 2007) already takes this into account following a catch allocation procedure, which allows identifying catches taken from each EEZ area (Watson et al., 2006a,b). Thus catch-based ecosystem indicators are robust to overseas fishing operations. Moreover, increased compliance with the Code results in better control and management of fishing activities in national waters on whatever fleets operate and the index takes this into account. Similarly, we assume that better compliance also results in developed nations ensuring their fleets operate on a sustainable basis abroad as well as at home.

Our study also highlights that those countries with initial lower sustainability of the fisheries in the 1990s, and high loss in production due to fishing, were those that 13 years later gained higher benefits from better adherence to the Code of Conduct, probably because the possibilities for marginal improvement were bigger. This result may encourage countries with limited resources to implement international agreements and benefit from an increase in ecosystem sustainability, supporting the idea of focusing on countries with little management capacity (Worm and Branch, 2012). Those countries with higher sustainability of the fisheries in 1990s showed ecological benefits with lower levels of compliance with the Code. However, even countries with higher initial ecological sustainability of the fisheries required adherence to the Code of Conduct to avoid ecosystem degradation, and the alignment degree required for those countries was even higher if ecological benefit were to be noticeable. This result may encourage countries with abundant resources to further implement international agreements to progress towards higher sustainable exploited ecosystems and towards an ecosystem-approach to fisheries management (FAO, 2003). Our results also validate empirically the original Code compliance study, which adopted 4/10 as a pass/fail threshold in the compliance with the Code assessment (Pitcher et al., 2009a,b).

Overall, our study conveys a positive message in the context of international agreements that are dealing with environmental issues: compliance with international agreements, such as the Code of Conduct for Responsible Fisheries by the Food and Agriculture Organization of the United Nations, can likely contribute to increasing sustainability (in this case sustainability of fisheries) regardless of the geographic position of the country. This is a fundamental issue since management effectiveness of world's marine fisheries management is generally low or very low (Mora et al., 2009), the expansion of fisheries and overexploitation of the marine ecosystems is increasing (Coll et al., 2008; Swartz et al., 2011), fisheries are rapidly evolving towards targeting lower trophic level organisms (Anderson et al., 2011), and the level of unreported and illegal catches globally is at least of the order of 40% (Agnew et al., 2009), while even those countries with abundant management initiatives and fisheries data still show 63% of fish stocks that need rebuilding (Worm et al., 2009). Fishing activities can have long lasting effects on ecosystem structuring and functioning (Jackson et al., 2001; Pauly et al., 2002; Lotze et al., 2006; Pitcher and Lam, 2010), so complying with well-established agreements may prevent further degradation and preserve ecological integrity, addressing food security on a long term basis, and avoiding stock collapses, biodiversity losses, and unwanted proliferations of low commercial species such as jellyfish and other high turnover organisms (Pitcher, 2008; Worm et al., 2006). Therefore, this study confirms that the implementation of existing commitments is essential if the sustainability of the ocean is to be improved, as it has been claimed recently under the context of the UN Conference on Sustainable Development ("Rio + 20") (Veitch et al., 2012).

Our study also alerts all concerned with fishery management to the serious ecological impacts of not honouring international initiatives to improve fisheries sustainability, such as the Code of Conduct for Responsible Fisheries by the Food and Agriculture Organization of the United Nations (FAO, 1995), since the inaction may imply further ecosystem degradation (Murawski, 2000). This degradation may occur even if limited management actions are

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undertaken, and is quicker than recovery. Due to the fact that the overall compliance with the Code of Conduct is still low or very low (Pitcher et al., 2009a,b), these results should encourage individual countries, regardless of socioeconomic situation, to adopt well-established fishery management measures with determination in order to increase the ecological sustainability of exploitation in marine ecosystems.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2012.10.017.

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