Sustainability **2013**, *5*, 1974-1993; doi:10.3390/su5051974

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

On the Non-Compliance in the North Sea Cod Stock

Sebastian Villasante [1,2,3,4,*], David Rodríguez-González [3,5] and Manel Antelo [3,6]

1 Department of Applied Economics, Faculty of Economics and Business Administration, University of Santiago de Compostela, Av. Burgo das Nacións s/n, 15782, Santiago de Compostela, Spain
2 Centro Nacional Patagónico (CENPAT), CONICET, 9120 Puerto Madryn, Chubut, Argentina
3 Campus Do* Mar, International Campus of Excellence, Spain
4 Karl-Göran Mäler Scholar, The Beijer Institute of Ecological Economics, P.O. Box 50005, SE-104 05, Stockholm, Sweden
5 Department of Quantitative Economics, Faculty of Economics and Business Administration, University of Santiago de Compostela Av. Burgo das Nacións s/n, 15782, Santiago de Compostela, Spain; E-Mail: david.rodriguez.gonzalez@usc.es
6 Department of Foundations of Economic Analysis, Faculty of Economics and Business Administration, University of Santiago de Compostela, Av. Burgo das Nacións s/n, 15782, Santiago de Compostela, Spain; E-Mail: manel.antelo@usc.es

* Author to whom correspondence should be addressed; E-Mail: sebastian.villasante@usc.es; Tel.: +34-981-563-100-(Extension 24427); Fax: +34-981-559-965.

Received: 8 March 2013; in revised form: 15 April 2013 / Accepted: 17 April 2013 / Published: 2 May 2013

Abstract: This paper estimates the economic value of the North Sea cod (*Gadus morhua*) stock under *recent catch* and several *recovery* scenarios. The research presents results on: a) what the value of catches and biomass would have been if the EU fishing fleet had followed the International Council for the Exploration of the Sea scientific recommendations (SRs) and Total Allowable Catches (TACs) in the 1986–2010 period; and b) what the value of catches and biomass will be for the 2010–2022 period if the fleet follows the current Common Fisheries Policy Reform (CFPR). Results show that the actual economic value of the stock for the 1986–2010 period has been US$7 billion, which is substantially lower than what would have been predicted had the industry followed the SRs (US$20.7 billion) or approved TACs (US$19.5 billion). Similarly, if catches do not follow the SRs or the approved TACs for the 2010–2022 period the estimated economic value of the stock is predicted to be lower than if they had done so. Further, the losses of non-compliance increase even when a scenario of 50% reduction of discards under the new

CFPR is considered. We also show that the status of the stock is strongly dependent on the trade-offs generated by both the non-compliance of scientific recommendations and by the short-term economic incentives of the fishing industry. With most fishery resources fully exploited or overexploited in Europe, opportunities for development lie primarily in restoring depleted stocks and catching fish more efficiently, as is the case of the North Sea cod stock.

Keywords: (Un)observed scientific advice; total allowable catches; economic value of North Sea cod (*Gadus morhua*) stock; Common Fisheries Policy Reform

1. Introduction

The overexploitation of the world's main commercial fisheries has been well documented [1–6]. Indeed, the latest scientific evidence shows that overexploitation of marine social-ecological systems is still high [7]. Costello *et al.* [8] recently found that small and large unassessed fisheries are also in substantially worse condition than assessed fisheries. This is undoubtedly the result of rapid technological development of fishing fleets [9,10], which lead to an increasing number of overexploited and collapsed fish stocks over time [11,12] and a reduction of marine ecosystem services [13,14].

One relevant example of this pattern is one of the most important commercial fisheries in the world, the North Sea cod [15–16]. After years of warnings from scientists, the large fisheries on the coast off Canada collapsed in 1992 [15–16] and there is strong evidence that this collapse was due to overfishing rather than environmental factors [17–20]. This was not only because Newfoundlanders enjoyed open access, but also because of the introduction of powerful fishing technologies under weak international controls [21].

With open access to the resource, all fishing vessels are competing for the same fish stocks: the more fish one catches, the fewer remain for others [2–3]. Thus, the outcome is a massive overuse relative to the fisheries management that would generate the greatest economic value from a given fishery [5]. Garcia and Grainger [22] estimated economic losses of US$8-16 billion per year for global fisheries around the world. The World Bank [23] also estimated that excess fishing might cost the world roughly US$50 billion a year in net economic losses. Similarly, Ainsworth and Sumaila [24] demonstrated that it was more inefficient under conventional valuation to harvest the cod stock to collapse than it would have been to sustain the population.

Recently, Sumaila *et al.* [25] revealed that resource rent, net of subsidies from rebuilt global fisheries, could increase from the current negative US$13 billion to positive US$54 billion per year, resulting in a net gain of US$0.6 to US$1.4 billion in present value over fifty years after rebuilding.

According to the study noted above, the European Union (EU) is the most affected area in the world, with a potential annual catch loss of 2.8 million tonnes and a negative resource rent of $4.8 billion per year. On the other hand, both subsidies to the fishing industry [9,26] and fishing overcapacity have led to a general decline of commercial fish stocks in the EU [1,9]. According to FAO [7], the Atlantic cod ranked 10th (in volume) worldwide in 2010 in the list of the most harvested species, but ranked 1st when only demersal species are considered, with a reported volume of 951 thousand t in that year.

Different studies have investigated the optimal fisheries management of the Atlantic cod fishery by using the scenario approach [27–29]. For example, Lindegren *et al.* [30] used a food-web model in order to show that only a holistic approach would save the Baltic cod from collapsing. In addition, substantial research efforts have been made on the economic incentives to recover cod populations in the North Sea [31], the social-ecological interactions between fisheries and aquaculture [32,33], the unobserved genetic diversity in fisheries management [16], the impact of size selectivity capture [34], the economic benefits of cooperative and non-cooperative fisheries management systems [35], and the recovery plans for cod stocks [36,37]. Froese *et al.* [38] also pointed out that long-term catches in Europe could be 63% higher on average under new harvest control rules, while profits could increase threefold within five years. Rather than demanding the highest possible catches immediately, fishers would be well advised to demand low increases in catches and a fixed upper catch below the theoretical maximum once the stock is fully recovered [39,40].

However, research on the economic dimension of the non-compliance of total allowable catches (TACs) by the fleet in the North Sea cod stock remains unexplored and unknown. This topic is particularly important to address especially when discussions on the Common Fisheries Policy reform (CFPR) are currently on going before being in force in 2014.

In this paper, we estimate the real biomass trend and the economic value of catches of the North Sea cod stock (International Council for the Exploration of the Sea areas IIIa West-Skagerrak, IV-North Sea and Division VIId-Eastern Channel), based on scientific reports published by ICES and the annual ex-vessel prices gathered from the Sea Around Us database [41]. The paper also presents estimated results on what the value of catches and biomass would have been if the EU fishing fleet had followed the ICES scientific recommendations (SRs) regarding quota allocation for 1986–2010 period; and what the value of catches and biomass would be for the 2010–2020 period if the EU fishing fleet follows the European Commission's proposal to be applied for the 2013–2022 period.

Although a full valuation of the total economic value of marine resources should include the direct, indirect, option, bequest, and existence values, they are not included in this study. Our study does not include, for example, the economic value of rebuilding to processors, retailers and other economic activities related to the fishery (*i.e.*, transport services, machinery and electronic equipment, *etc.*). Inclusion of all these other values would involve a much more extensive research that is out of the scope of this study.

2. Managing Fishery Resources under TAC Regulation

Even though most nations are committed in theory to protect marine ecosystems, it is still common—usual in fact—for fishery scientists to recommend catches based on the health of a given commercial fish stock, combined with profitability issues, in making their SRs. On the one hand, international and national strategies place high value on protecting marine ecosystems, while in practice catches are based on science which does not necessarily seek to protect fundamental ecosystem functions. For example, under the CFPR, ICES is typically requested to provide catch advice on a stock-by-stock basis, as most of the stocks on which ICES advises are managed using stock-specific TACs, although other fishery management measures are frequently used as well.

In the case of TAC regulation, when the volume of catches that are allowable for each State is annually determined, the European Commission uses SRs made by scientists from ICES through its Advisory Committee for Fisheries Management, which takes into account the scientific advice of the Scientific, Technical, and Economic Committee on Fisheries and Aquaculture. Then, the European Commission publishes a proposal for a TAC scheme. Finally, after arduous negotiations, the final proposal is approved by the European Council [42]. Later on, these TACs are distributed amongst member States, following an automatic mechanism known as the *principle of relative stability*, where three elements are taken into consideration: (i) catches made by member States in the 1973–1978 period, (ii) the loss of fishing possibilities in third countries as a consequence of the establishment of the Economic Exclusive Zones and, (iii) special needs of fishing dependent communities over time.

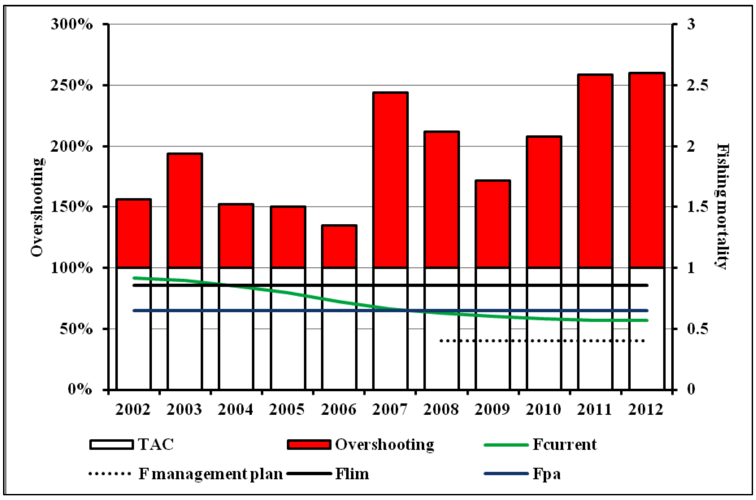
The practice showed that fragile commitment agreements have prevailed, by simplifying the allocation of fishery resources to a pragmatic negotiation in which most intervening parties are satisfied, without considering the impact that the TAC system may have both on resources and on the fishing industry [36]. As result, the implementation of the TAC mechanism has received widespread criticism by the scientific community [1,9,29,36,38,39,43,44]. These criticisms range from arguments based on the negative impact of TACs on marine ecosystems in the North Atlantic Ocean [45], the need to discuss the analysis of economic benefits [46], the limitations to the individual rights of fishing [26], the generation of a considerable volume of illegal fishing [47], the high impacts on the sustainability of deep-sea species [44], and the lack of enforcement by national authorities [36,44].

As a result of the mismanagement of the fishery [29,44,48,49], the spawning stock biomass (SSB) declined to the lowest historical level in 2006 with catches consisting mostly of immature fish [48]. Recruitment figures since 2000 have also been low. The proportion of discards is still high relative to the historical period, and the main sources of uncertainty are the estimation of unallocated removals and the assumption of fishing mortality (F) [48]. In December 2008 the European Council (Council Regulation (CE) No. 1342/2008 of 18 December 2008, establishing a long-term plan for cod stocks and the fisheries exploiting those stocks and repealing Regulation (EC) No 423/2004) agreed on a new cod management plan adopting the new system of effort management and a target F of 0.4. However, ICES [48] pointed out that although there has been a gradual reduction in the value of F and discards in the last years, the management plans for North Sea cod have not controlled F as envisaged (See also Table TS2 of the Supplementary Material).

To illustrate, Figure 1 shows that landings of North Sea cod are, in average, 2.2 times higher than TACs under the current management plan ($F_{management\ plan}$) in the 2008–2012 period, and 1.7 times higher in the previous period (2002–2007) to the implementation of the plan. In a sense, this overshooting level (*i.e.*, the degree of compliance of fishing quotas) may be understood as an unsuccessful result of the TAC mechanism due to the lack of enforcement of the management plan. But there are other factors that complicate the current stock assessment. As Ulrich *et al.* [49] pointed out, mixed fisheries simulations provide an indication of the potential implementation error in North Sea cod advice, with current F being higher than stipulated in the cod long-term management plan.

Moreover, since the introduction of effort control associated with the cod long-term plan (Council Regulation (CE) No. 1342/2008), there is some evidence that fishing effort could be displaced towards other lobster grounds where effort control has not been put in place yet. Kraak *et al.* [50] also found that fishing mortality reductions have not been achieved since the implementation of the cod plan.

Figure 1. Fishing effort and overshooting from the North Sea cod long-term management plan.



Source: own elaboration from [45]. F_{pa} stands for precautionary reference point for fishing mortality (mean over defined age range) and F_{lim} for limit reference point for fishing mortality (mean over defined age range).

Furthermore, ignoring the human dimension of fishers as reactive agents in the design, the impact assessment, and the annual implementation of the measures has contributed to the failure to adequately implement the plan and achieve its objectives [51]. As Folke *et al.* [51] and Villasante [52] already stated, if current unsustainable paths of EU fisheries are to be reversed humans need to be included in the decision-making process as a component of EU marine social-ecological systems. With an improved understanding, recommendations to ensure ecosystem performance and resilience can be developed that incorporate the view of marine ecosystems as complex adaptive systems with non-linearities, discontinuities, and multiple-stability domains and thresholds. However, it is important to highlight that although ecosystem-based management explicitly includes humans as part of social- ecological systems, in practice, current interpretations of the approach fall short of any real consideration [51].

3. Material and Methods

3.1. The North Sea cod Stock (Gadus Morhua)

The North Sea cod is an epibenthic-pelagic species that is widely distributed in a variety of habitats [53]. The cod populations in EU waters under TAC regulation included in this study are found in the following ICES areas: IIIa West (Skagerrak), IV (North Sea), and Division VIId (Eastern Channel). North Sea cod stocks are mainly exploited by fleets from Belgium, Denmark, the Netherlands, Germany, France, Sweden, Norway, and the United Kingdom [48]. (See Table TS1 of the Supplementary Material for term definitions and detailed data used in this paper.) According to estimates reported by ICES [45] and Agnew *et al.* [47], these fleets account for most of the total removals of the species from the sea—including official catches, discards, and Illegal, Unreported and Unregulated (IUU) fishing—across the EU in the 1986–2010 period.

3.2. Using (three) Scenarios to Estimate the Economic Value of North Sea Cod

The economic value of the biomass of North Sea cod in the ICES areas mentioned above are estimated under various scenarios and periods by following the methodology proposed by Antelo *et al.* [54]. Production of a fish stock is the sum of the population weight (biomass) augmented by recruitment and growth, minus the loss from natural mortality. Fishing mortality (F) is the only variable in the production function that can be directly controlled by fisheries management. Fisheries management cannot control spawning-stock biomass (SSB), it can only influence it through F [55].

Production can be highly variable but, on average, it is related to stock size (often expressed as SSB), which in turn depends on F. That is, for each F, there is a long-term average production and an average stock size. The relationship between F, production, and stock size is called the production function [45]. Surplus production, in turn, is the catch that can be harvested without changing the stock size. Catches will be dependent on the level of TACs allocated for the fishery. This is why we assume that TACs are correlated with a given F over time [45].

In sum, we use a surplus production model to estimate the stock value according to the time series data of the total landings and biomass provided by ICES [49]. Our goal is to compare the real situation of the stock (by using published ICES reports with information of catches, discards and IUU catches) compared to different hypothetical future scenarios. This method requires estimating the volume of future biomass, catches and prices. To estimate the value of the stock biomass, we employ a surplus production function to time series data for total landings and biomass provided by [56]. The resulting production function is given by:

$$TB_t = TB_{t-1} + F(\cdot) - C_{t-1} \tag{1}$$

where TB_t stands for total biomass in period t, TB_{t-1} measures total biomass in period $t-1$, $F(\cdot)$ is a function that measures natural growth of the stock, and C_{t-1} denotes the volume of catches (*i.e.*, reported catches, discards and Illegal, Unreported and Unregulated catches) in period t-1. In addition, because the volume of discards are not marketed at seafood markets, they were not included in the economic valuation of the stock, despite that the higher the volume of discards, the higher the risk to reduce the abundance of the stock. We choose a logistic function for $F(\cdot)$ and the production function stated in (1) becomes

$$TB_t = TB_{t-1} + g \cdot \left(1 - \frac{TB_{t-1}}{TB_0}\right) - C_{t-1} \tag{2}$$

where g is the intrinsic rate of population growth and TB_0 measures the unexploited total biomass. The value for total biomass at the initial time point during the analysis period was taken from ICES reports on the cod populations selected. Particularly, TB_0 was estimated as a fraction of the target biomass that produces a maximum sustainable yield (MSY), B_{msy}; specifically, $B_{\text{msy}} = 50 - 75\%$ of TB_0 [57]. In particular, we assume here that $B_{\text{msy}} = 62.5\%$ of TB_0. It has been a traditional fisheries objective to achieve single species MSY, and most management regimes have been built around this framework.

Values of $B_{\text{msy}} = 2{,}345{,}494$ tonnes and $g = 0.57$ were taken from [56]. We used the intrinsic rate of population increase rate used by Froese and Proelss [56] for 54 European Union fish stocks. The intrinsic rate of population increase g as obtained iteratively from the equation below described in [56]:

$$e^{g \cdot t_m} - e^{g \cdot (t_m - 1) - M} - \alpha = 0 \tag{3}$$

where α is the slope at the origin of the spawner-recruitment curve when the number of recruits is taken as the number surviving to maturity and spawners are expressed in numbers, *i.e.*, α is the spawner-recruitment curve when the spawners or the maximum annual reproductive rate at low population densities.

Data for ex-vessel cod prices were taken from Sea Around Us database and are expressed in real 2000 prices once conveniently adjusted by the consumer price index. The primary data in the Sea Around Us database are nominal ex-vessel prices, in most case obtained by dividing officially reported landed values by landings. Ex-vessel prices and landed values are presented in US$ to allow a uniform basis for comparison. Given that the starting point for the data is always local ex-vessel prices in local currency, we converted them into US$ equivalents. In the Sea Around Us database, nominal and real ex-vessel prices and landed values are presented. The real values were determined by using local consumer price indices (CPI) to convert local nominal ex-vessel prices into real (year 2000) ex-vessel prices. These are then converted into year 2000 US$ equivalents.

Here two periods were considered: the 1986–2010 period and the 2010–2022 period. The first period is intended to evaluate how the value of catches and the value of stock itself evolved before the CFPR and the second one to assess how the pattern could be after the CFPR. Although the CFPR will be in force in 2013, it is necessary to "extend" the period of analysis to 2010–2022 in order to have an initial value of the biomass as a parameter for the model. Since the value of the biomass closest to the 2013–2022 period is that which corresponds to year 2010, the 2010–2022 period is examined.

3.2.1. The 1986–2010 Period

In this period the (real) economic value of landings and that of the stock in the end of the period is calculated by using total removals of cod from the sea (*i.e.*, reported catches, discards and IUU catches). We also estimated the economic value of landings as well as that of the stock at the end of the period if the reported catches had the corresponding SRs and TACs. This situation is referred as *Scenario 1*. As stated by Hilborn and Walters [55], when a given stock recovers over time, the fishers' behaviour usually lead to an increase catches. That is, it is necessary to evaluate what would have happened if fishers followed the simulated SRs and TACs in order to investigate whether the simulated trajectory of the biomass would have deviated from its trajectory. This requires the endogenization of the SRs and the TACs [55] by formally applying (1) and (2). It is important to highlight that when endogenezing catches by using the surplus production model and assuming that future catches will follow SRs and/or TACs, the results of the model should indicate that the stock tends to recover over time. Therefore, this does not require a reduction of the catches in the future because of the better status of the stock.

As Antelo *et al.* [54] proposed, the proportion of SRs and TACs over biomass is estimated by using biomass data reported by ICES. In the case of the North Sea cod, SRs represented in average 40% of the total biomass reported by ICES, while TACs accounted in average for 42% of the total biomass. Both values were calculated as the average values of SRs/catches and TACs/catches respectively in the 1987–2000 period. To calculate these average values, the 2001–2010 period was not included because scientists from ICES directly recommended the closure of the fishery [48]. (See TS1 of the Supplementary Material.) Additionally, the annual ex-vessels prices of cod provided by Sea Around Us database are used as a proxy for average prices of North Sea cod because neither ICES nor FAO reported information on ex-vessel prices of catches in the 1986–2010 period.

Using the total landings reported each year of this period and the price per tonne of the landings, we estimated a linear relationship between cod catches and prices (in US$ per tonne). This relationship, which attempts to quantify the inverse demand function of North Sea cod, is given by:

$$p_t(C_t) = 1{,}594.77 - 5{,}51 \cdot 10^{-4} C_t \quad (4)$$

where p_t denotes the cod price for each year t and C_t indicates the reported catches (in tonnes) of cod for each year t. The results provided by the econometric models used in this paper have been obtained by using the free software gretl v. 1.9.11 [58]. The value of R^2 coefficient of the estimation given in (4) amounts to 0.3646. However, the value of Durbin-Watson statistic associated with this linear model, 0.6830, suggests the existence of autocorrelation between the residuals of the model. Indeed, the analysis of the autocorrelation and partial autocorrelation functions confirms the existence of second order autocorrelation.

Hence, the estimate given by equation (4) is not accurate. For that reason, we developed a more complex model than (4) to quantify the inverse demand function as follows:

$$p_t(C_t) = \beta_0 + \beta_1 \cdot C_t + \varepsilon_t \quad (5)$$

where β_0 and β_1 denote the coefficients of the regression model and ε_t represents the residuals of the regression model for each year *t*. Under second order autocorrelation (AR2), residuals are given by the model:

$$\varepsilon_t = \phi_1 \cdot \varepsilon_{t-1} + \phi_2 \cdot \varepsilon_{t-2} + \mu_t \quad (6)$$

where ε_{t-1} and ε_{t-2} denote residuals of the regression model for years $t-1$ and $t-2$ respectively, ϕ_1 and ϕ_2 indicates the coefficients of the model, and μ_t the residuals that are distributed as white noise.

In order to estimate this autoregressive model we used the Cochrane-Orcutt method and the results are given by the following expressions:

$$\widehat{p_t}(C_t) = 1{,}575.71 - 4{,}969 \cdot 10^{-4} C_t + \widehat{\varepsilon_t} \quad (7)$$

$$\widehat{\varepsilon_t} = 1.106\varepsilon_{t-1} - 0.732\varepsilon_{t-2} \quad (8)$$

where all parameters are significant at the 1% level. The value of R^2 coefficient of the estimation given in equations (7) and (8) is 0.8309 and the value of Durbin-Watson statistic is 1.6458, which is within the accepted bounds that reject the existence of autocorrelation. Cod catches are therefore endogeneized under the assumption that they would follow SRs and TACs [56].

In each scenario and for each year *t*, the economic value of catches is calculated by multiplying the volume of catches in that year by unit prices. Such a price is then obtained by including the volume of catches (and not the remaining stock) into the demand function given by equations (7) and (8). Hence, we can estimate the stock value in economic terms. Finally, the discounted economic value of the remaining stock under each scenario is obtained by multiplying the volume of biomass in each period t by the estimated price of the stock for that year. To discount economic values over time, we assume an interest rate $r = 0.025$. It is the long-term interest rate currently observed on financial markets and also the rate that many authors (for example, [59–61]) consider more appropriate to determine discounting factors in goods and services from the natural environment.

Figure 2 illustrates the predictive capacity of the surplus production model given by equation (2). In particular, it can be seen that when we compare data from reported biomass by ICES for the 1986–2010 period and simulated data by our model, Figure 2 shows a similar pattern over time. In fact, the correlation coefficient between reported values and simulated values amounts to 0.875. This finding allows us to validate the surplus production model used which is necessary to estimate the evolution of the biomass under different scenarios for which ICES do not provide data. Specifically, these scenarios are either simulated contexts (evolution of biomass if catches would have been followed SRs and TACs during the 1986–2010 period) or future scenarios (*i.e.*, future catches, SRs and TACs during the 2010–2022 period).

Figure 2. Real biomass of North Sea cod reported by International Council for the Exploration of the Sea *vs.* Estimated biomass.

Source: own elaboration from [45,48] and our model.

3.2.2. The 2010–2022 Period

As recognized by the European Commission Green Paper (COM (2009) 163 final) and the Communication from the Commission on Reform of the CFP (COM (2011) 417 final), the resource allocation system based on the TACs and quota regime and inspired by the principle of relative stability will maintain its basic principles. In addition, the European Commission proposal provides for the implementation of a ban on discards. Assuming this new approach, and considering that this policy is overly optimistic, we adapted our model to simulate the cod biomass (both in volume and value) for 2013–2022 period under two scenarios that are more realistic than that provided by the proposal of the CFPR. Thus, for 2010–2022 period two different scenarios are analysed; namely:

(a) The estimated economic value of the stock is calculated considering that the pattern of catches, discards and IUU catches reported for 1986–2010 period will be maintained throughout the 2010–2022 period (*Scenario 2*), and

(b) The estimated economic value of the stock is also calculated by assuming a 50% reduction of discards and catches from IUU fishing during the 2010–2022 period (*Scenario 3*).

4. Results and Discussion

4.1. The Real Economic Value of North Sea Cod Stock (1986–2010)

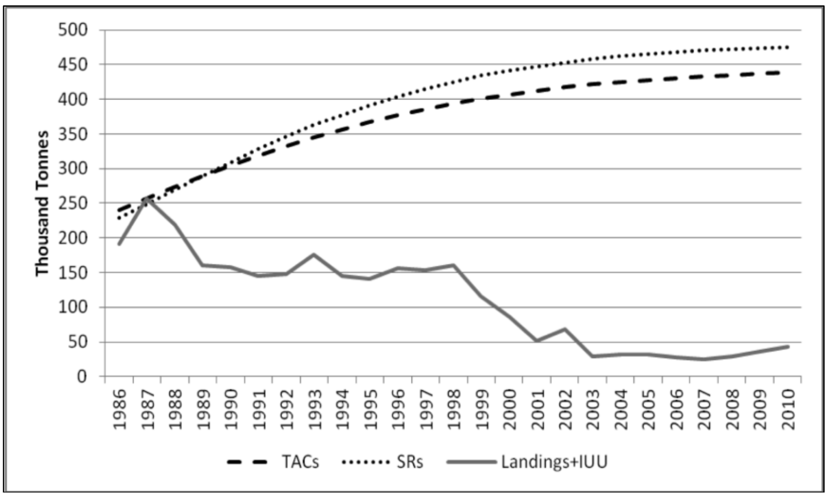
Considering the current prices of cod observed in the seafood market for the 1986–2010 period, and using 2.5% as the long-term interest rate to determine the discount factor over time, the economic value of North Sea cod catches have been about US$7 billion as recorded in Table 1. In addition, if catches have had followed the SRs, both the volume of catches (Figure 3) and their economic value (Figure 4) would have been much greater than their current values.

Table 1. Discounted economic value of catches and the North Sea cod stock (in billion US$ Real value).

	Landings value (1986–2010)	**Biomass value (2010)**	**Total stock value (1986–2010)**
Real catches	6.81	0.28	7.09
TACs	18.16	1.36	19.52
SRs	19.19	1.55	20.74

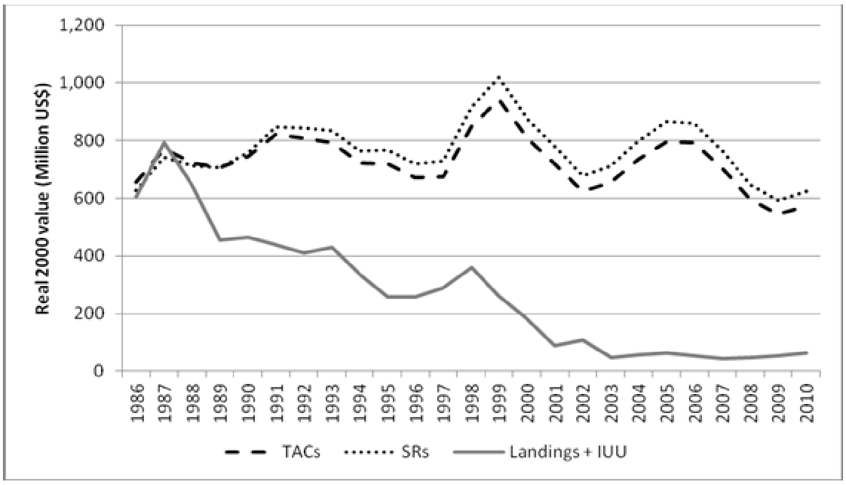
Source: own elaboration from [45,48] and Sea Around Us Database. Estimated values provided by the model are shown in italics.

Figure 3. Real trends of North Sea cod catches *vs.* Estimated trends of catches under scientific recommendations (SRs) and Total Allowable Catches (TACs) regimes (1986–2010).



Source: own elaboration from [45,48] and Sea Around Us Database.

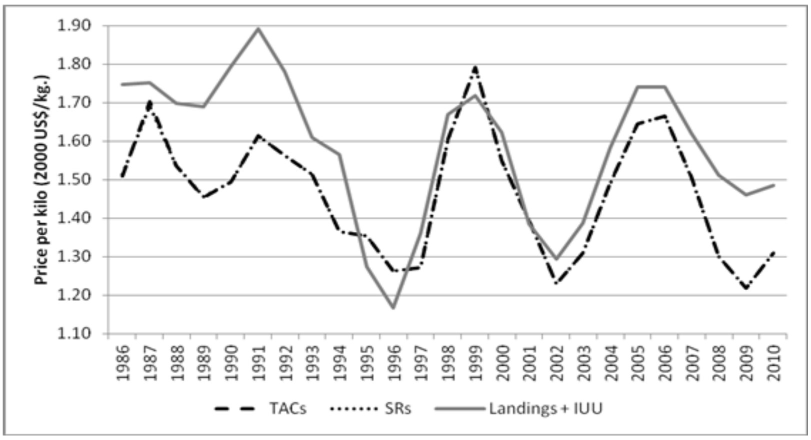
Figure 4. Real economic value of North Sea cod catches *vs.* Discounted economic value of catches under SRs and TACs (1986–2010).



Source: own elaboration from [45,48] and Sea Around Us Database.

In particular, the economic value of catches would have reached US$20.7 billion due to the recovery of stock biomass. On the other hand, if catches have had followed the TACs, their value would have reached US$19.5 billion (Table 1). The reason is that with the increase of stock abundance, the seafood market would have responded favourably to this new situation. The fishing industry would not be the only beneficiary of the increased economic value of its catches; it would also benefit consumers who would have increased access to a high protein food source, which in turn would contribute to achieve the following *Millennium Development Goals* (MDG) [13,62]: (a) *Goal 2* (assuming that if through fishery activities incomes increase, it is expected that school attendance is likely to improve), (b) *Goal 3* (Women are further empowered through trading in fish, and by facilitating various kinds of Enterprise), (c) *Goals 4 and 5* (Child and maternal health conditions would improve if fisheries can contribute either directly or indirectly to reducing hunger and improving nutritional levels) and (d) *Goal 7* (Properly managed fisheries ensure that environmental capital and services are preserved for future generations) [62].

Figure 5. Real prices trend for the North Sea cod *vs.* Estimated prices trend under SRs and TACs (1986–2010).



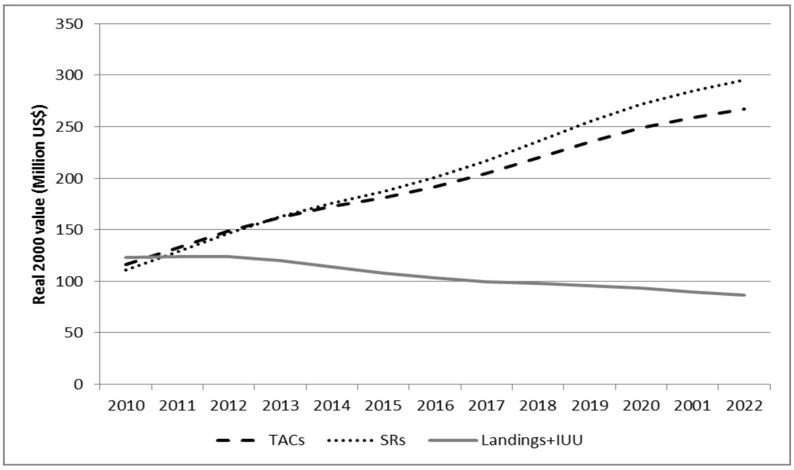
Source: own elaboration from [45,48] and Sea Around Us Database.

Figure 5 shows that the increase of total biomass that would have occurred if the EU fishing fleet had complied with TACs would have resulted in a lower price per tonne landed over time. In addition, these lower values are observed not only under TACs but also under SRs estimates due to the fact that the values used to estimate prices by using the model presented in equations (6) and (7) are similar.

4.2. Estimating the Economic Value of North Sea Cod Stock Period Under Scenarios 2 and 3

In this subsection two estimated economic values of the stock for the 2010–2022 period are presented. First, the value for estimated catches and the value of the biomass in the end of that period once the SRs and the TACs have been estimated year by year (*Scenario 2*). Second, the same is done taking into account the CFPR's proposal of a 50% reduction of discards in the 2013–2022 period (*Scenario 3*). The discards reduction proposed by the European Council (Press release 3225th Council Meeting, Agriculture and Fisheries, Brussels, 25–26 February 2013) is higher (90%) than the one used in this paper. However, we assume a more conservative value taking into account the history of the European negotiations in the field of fisheries management. The estimated value of cumulated catches plus that of the biomass in year 2022 under the new CFPR is intended to illustrate what might happen with the North Sea cod fishery in the future (Figure 6).

Figure 6. Estimated biomass of North Sea cod stock under the Common Fisheries Policy Reform (CFPR) (2010–2022) (*Scenario 2*).

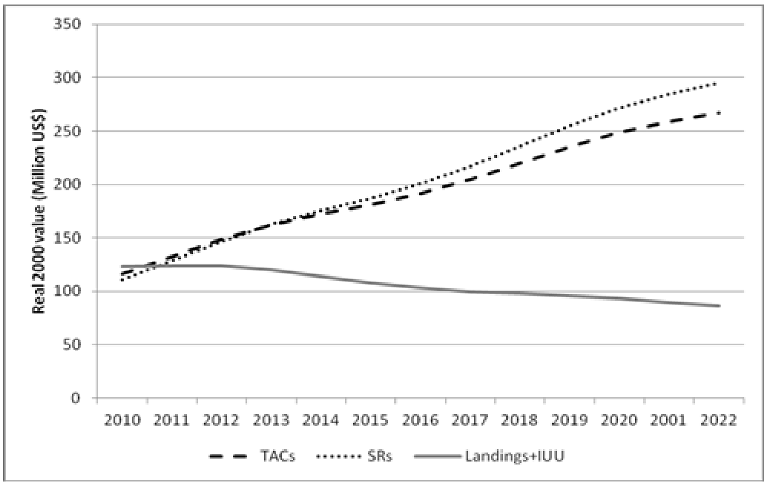


Source: own elaboration from [45,48] and Sea Around Us Database.

Although this estimate represents a simplification of the potential population dynamics of the stocks, the future path of the fishery will be determined largely by actual catches [23,25]. Future catches will also be influenced by any variation in the growth of the stock, which may cause an increase or decrease in future biomass depending on the degree of exploitation [23,25]. As noted above, under *Scenario 2* it is assumed that catches do not follow the SRs and TACs proposals for each year, but their pattern continues to be similar to that of the 1986–2010 period.

As Figure 7 shows, the value of annual catches if they respected SRs and TACs would be substantially higher than the real economic value of reported catches. In that case, the actual economic value of catches would amount to about US$145 million annually and the value of remaining biomass in 2022 to only US$93 million, which is substantially lower than US$ 271 and 248 US$ million respectively, predicted by our model if catches follow the SRs and TACs.

Figure 7. Estimated catches of North Sea cod stock under the Common Fisheries Policy Reform (CFPR) (2010–2022) (*Scenario 2*).



Source: own elaboration from [45,48] and Sea Around Us Database.

The total economic value of the catches during this period would amount to only US$1.3 billion, which is well below the value if TACs or SRs were followed (US$2.5 billion and US$2.6 billion, respectively). In addition, the economic value of the remaining stock in 2022 would be substantially lower with respect to the cases in which the catches would follow both the SRs and the TACs as shown in Table 2.

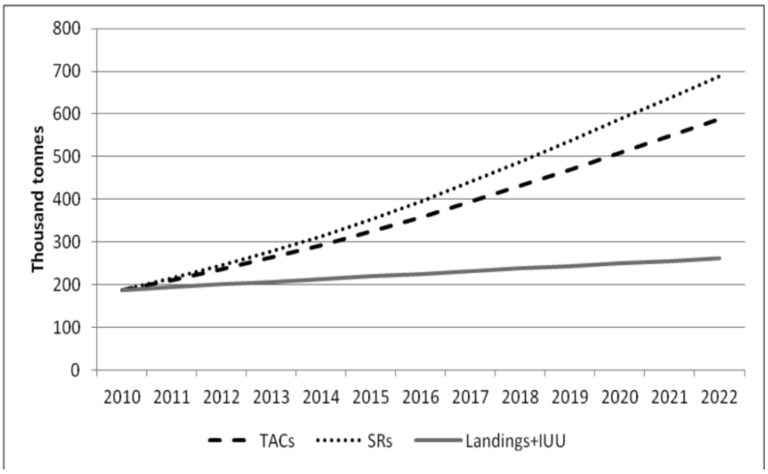
Table 2. Discounted economic value of the North Sea cod stock (2010–2022) (*Scenario 2*) (in billion US$ real value).

	Landings value (2010–2022)	Biomass value (2022)	Total stock value (2010-2022)
Real catches	*1.38*	*0.20*	*1.58*
TACs	*2.54*	*0.67*	*3.21*
SRs	*2.67*	*0.78*	*3.45*

Source: own elaboration from [45,48] and SAUP Database. Estimated values provided by the model are shown in italics.

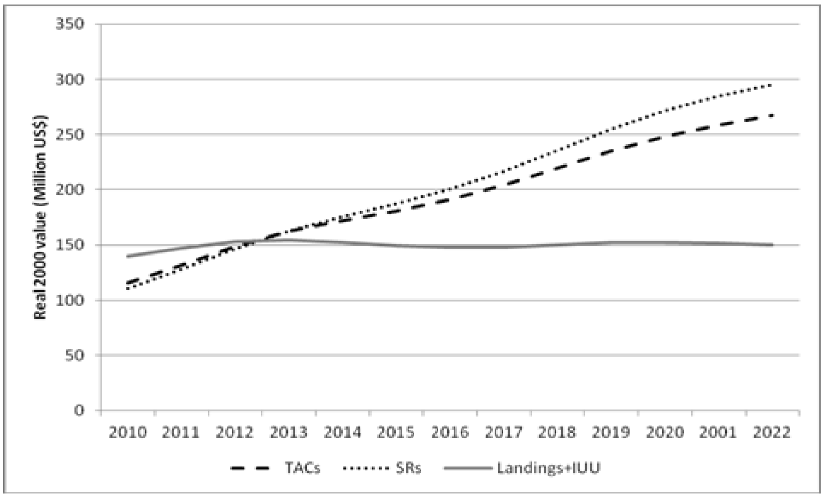
On the other hand, the estimated biomass (both in volume and value) under *Scenario 3,* which considers a 50% reduction of discards during the new CFPR for 2013–2022 period, recovers faster because of the restrictive measures that could potentially adopt the European Commission (see Figures 8 and 9).

Figure 8. Estimated biomass of North Sea cod under the Common Fisheries Policy Reform (CFPR) (2010–2022) with a 50% discard reduction (*Scenario 3*).



Source: own elaboration from [45,48] and Sea Around Us Database.

Figure 9. Discounted economic value of North Sea cod catches under the Common Fisheries Policy Reform (CFPR) with a 50% discard reduction (2010–2022) (*Scenario 3*).



Source: own elaboration from [45,48] and Sea Around Us Database.

In fact, assuming that the catches follow a 50% discard reduction proposed by the European Commission, the economic value of catches during the whole period would amount to US$1.9 billion as reflected in Table 3.

Table 3. Discounted economic value of the North Sea cod stock under the CFPR with a 50% discard reduction (2010–2022) (*Scenario 3*) (in billion US$ real value).

	Landings value (2010–2022)	**Biomass value (2022)**	**Total stock value (2010–2022)**
Real catches	*1.95*	*0.31*	*2.26*
TACs	*2.54*	*0.67*	*3.21*
SRs	*2.67*	*0.78*	*3.45*

Source: own elaboration from [45,48] and SAUP Database. Estimated values provided by the model are shown in italics.

By contrast, if the fishing industry harvests the catches recommended by scientists, their economic value would be US$2.6 billion, and the cumulated value of the fishery would amount to US$3.4 billion, which is higher than the cumulated value if catches operates on a short-term basis rather than a long-term horizon. Indeed, current catches are so high that the economic value of the remaining biomass in the future would amount only to US$149 million.

5. Conclusions

The main contribution of this paper is to address an important although rarely discussed issue: the continual failure of fishery managers (not just in the EU) to promote long-term industry stability ahead of short-term pressures from fishers trying to pay off their bank loans with immediate profits. As suggested by the results presented here, the fishing industry seems to prefer high short-term profit with an uncertain industry future, over lower immediate profits with greater chance of both ecological and economic sustainability. This is consistent with the predictions made by theoretical models of fisheries management [22–25,29,31,36,38–41,55,63–67], including the emergence of the competitive fishermen's behaviour as the primary outcome [42,57,64]. Although direct policy implications from the findings of this paper are limited in scope because of the hypothetical scenarios, it provides a good point of departure to incorporate new scientific evidence into current CFPR's discussions.

It is important to highlight some limitations of the study related not only to the data used but also due to the fact that the stock assessment of this fishery is subjected to a number of uncertainties. First, there is a discrepancy between the information coming from commercial catch and the scientific survey used for tuning the assessment, resulting in the estimation of unallocated mortality and catches [48]. Second, the proportion of landings, discards, and unallocated (unaccounted) removals is difficult to anticipate, and this is a weakness in the estimation of predicted landings, and thus of the TACs advice [48]. Third, there is no documented information on the source of these unaccounted removals; while it has been previously assumed that they originate mostly from fishing activities, changes in natural mortality may also have an influence [48]. Fourth, revision of recruitment data may influence the stock-recruitment relationship and may therefore affect the estimates of reference points [48].

Climate change will further exacerbate the challenges currently facing global fisheries, as it has begun to alter ocean conditions, particularly water temperature and biogeochemistry [68]. Changes in ocean temperature will change the natural growth rate of the resource [69], which will have economic impacts on the fishing industry [70]. Because the geographical location and range of many fish stocks are likely to change, possibly quite dramatically [68], allocation of TACs shares to member States may become increasingly anomalous, thereby resulting in various kinds of strain on the CFPR and the principle of relative stability [71]. Under these circumstances, harvest rates should be lower than has been assumed, especially when the level of uncertainty is high [63].

In addition, it is also important to emphasize that we pointed out the existence of social-ecological synergies and trade-offs between biological (in the form of scientific recommendations, TACs and quotas) and economic (*i.e.*, value of landings and prices) dimensions of the North Sea cod. We also showed that the status of the stock is strongly dependent on the trade-offs generated by both the non-compliance of scientific recommendations and by the short-term economic incentives of the fishing industry. Cascading social-ecological interactions can create vulnerabilities, but can also provide important opportunities to develop more sustainable paths and methods to assess the performance of fishery resources with humans considered to be an integral piece of the puzzle [72]. In other words, it is highly necessary to shift from simply managing natural resources with a vision of the environment as an externality, to fostering the stewardship of interdependent social-ecological systems [52,72–74].

With most fishery resources fully exploited or overexploited in Europe, opportunities for development lie primarily in restoring depleted stocks and catching fish more efficiently, as is the case of the North Sea cod fishery. Our study also demonstrates that while policy makers must assist fishermen during the early years of the program, fishermen will experience greater landings and profits in following years [56]. Fish populations could strongly increase and generate more economic output if fishing pressure was reduced. The next CFPR offers a great opportunity to implement a rebuilding program that would allow EU member States to substantially increase economic returns. This would mean that at the end of the next CFPR, most fish stocks would have recovered and the fishing industry could obtain positive resource rents, while maintaining employment and income in coastal communities.

Supplementary Material

Supplementary can be accessed at: http://www.mdpi.com/2071-1050/5/5/1974/s1.

Acknowledgments

The authors gratefully acknowledge four anonymous reviewers for insightful comments and suggestions. The authors are also grateful to Prof. Juan Carlos Estévez (USC) for his valuable assistance in the statistical analysis of the model. The authors also acknowledge valuable discussions and suggestions during the *XIII Workshop of the Latin American and the Caribbean Environmental Economics Program* (LACEEP) (San José de Costa Rica, May 19–22nd 2012), and the *Subregional Workshop for South America on Valuation and Incentive Measures* (Santiago de Chile, May 14–17th 2012) organized by the UNEP Program and the Convention on Biological Diversity (CBD). SV acknowledges the financial support from the Norwegian Research Council, the Campus do Mar-International Campus of Excellence, and the Spanish Agency for International Development Cooperation (AECID). MA acknowledges financial aid from Galician Regional Government (Xunta de Galicia) through grant INCITE 09201042PR.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Khalilian, S.; Froese, R.; Proelss, A.; Requate, T. Designed for failure: A critique of the Common Fisheries Policy of the European Union. *Mar. Policy* **2010**, *34*, 1178–1182.
2. Pauly, D.; Christensen, V.; Guénette, S.; Pitcher, T.; Sumaila, U.R.; Walters, C.J.; Watson, R.; Zeller, D. Towards sustainability in world fisheries. *Nature* **2002**, *418*, 689–695.

3. Christensen, V.; Guénette, S.; Heymans, J.J.; Walters, C.J.; Watson, R.; Zeller, D.; Pauly, D. Hundred-year decline of North Atlantic predatory fishes. *Fish. Fish.* **2003**, *4*, 1–24.
4. Hilborn, R.; Branco, T.; Ernst, B.; Magnusson, A.; Minte-Vera, C.V.; Scheuerell, M.D.; Valero, J.L. State of the world's fisheries. *Annu. Rev. Env. Res.* **2003**, *28*, 359–399.
5. Heal, G.; Schlenker, W. Economics: Sustainable fisheries. *Nature* **2009**, *455*, 1044–1045.
6. Gutiérrez, N.; Hilborn, R.; Defeo, O. Leadership, social capital and incentives promote successful fisheries. *Nature* **2011**, *470*, 386–389.
7. The Food and Agriculture Organization of the United Nations (FAO). In *State of the World's Fisheries and Aquaculture 2012*; FAO: Rome, Italy, 2012.
8. Costello, C.C.; Ovando, D.; Hilborn, R.; Gaines, S.D.; Deschenes, O.; Lester, S.E. Status and solutions for the world's unassessed fisheries. *Science* **2012**, *26*, 517–520.
9. Villasante, S.; Sumaila, U.R. Estimating the effect of technological efficiency on the European fishing fleet. *Mar. Policy* **2010**, *34*, 720–722.
10. Anticamara, J.A.; Watson, R.; Gelchu, A.; Pauly, D. Global fishing effort (1950–2010): Trends, gaps, and implications. *Fish. Res.* **2011**, *107*, 131–136.
11. Gelcich, S.; Hughes, T.P.; Olsson, P.; Folke, C.; Defeo, O.; Fernandez, M.; Foale, S.; Gunderson, L.H.; Rodriguez-Sickert, C.; Scheffer, M.; *et al.* Navigating transformation in governance of Chilean marine coastal resources. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 16794–16799.
12. Kleisner, K.; Zeller, D.; Froese, R.; Pauly, D. Using global catch data for inferences on the world's marine fisheries. *Fish. Fish.* **2012**, doi: 10.1111/j.1467–2979.2012.00469.x.
13. Millennium Ecosystem Assessment (MEA). *Ecosystems and human well-being: Synthesis*; Island Press: Washington, DC, USA, 2005.
14. Worm, B.; Barbier, E.B.; Beaumont, N.; Duffy, J.E.; Folke, C.; Halpern, B.S.; Jackson, B.C.; Lotze, H.K.; Micheli, F.; Palumbi, S.R.; *et al*. Impacts of biodiversity loss on ocean ecosystem services. *Science* 2006, *314*, 787–790.
15. Schrank, W.E. The Newfoundland fishery: Ten years after moratorium. *Mar. Policy* **2005**, *29*, 407–420.
16. Sterner, T. Unobserved diversity, depletion and irreversibility: the importance of subpopulations for management of cod stocks. *Ecol. Econ.* **2007**, *61*, 566–574.
17. Myers, R.; Hutchings, J.; Barrowman, N. Why do fish stocks collapse? The example of Cod in Atlantic Canada. *Ecol. Appl.* **1997**, *7*, 91–106.
18. Myers, R.; Hutchings, J.; Barrowman, N. Hypotheses for the decline of Cod in the North Atlantic. *Marine Ecol. Prog. Ser.* **1996**, *138*, 293–308.
19. Hutchings, J. Collapse and recovery of marine fisheries. *Nature* **2000**, *406*, 882–825.
20. Khan, A. A market chain analysis of Northern Gulf cod fisheries Pre- and post collapse: Implications for resource sustainability and economic viability. In Proceedings of IFFET 2010 Conference, Montpellier, France, 13 July 2010.
21. Finlayson, A.C.; McCay, B.J. Crossing the threshold of ecosystem resilience: the commercial extinction of northern cod. In *Linking Social and Ecological Systems—Management Practices and Social Mechanisms for Building Resilience*; Berkes, F., Folke, C., Colding, J., Eds.; Cambridge University Press: Cambridge, UK, 1998; pp. 311–338.

22. Garcia, S.M.; Grainger, R.J.R. Gloom and doom? The future of marine capture fisheries. *Philos. T Roy. Soc. B* **2005**, *360*, 21–46.
23. World Bank and FAO. *The Sunken Billions: The Economic Justification for Fisheries Reform*; World Bank: Washington, DC, USA, 2009.
24. Ainsworth, C.H.; Sumaila, U.R. Intergenerational valuation of fisheries resources can justify long-term conservation: a case study in Atlantic cod (*Gadus. morhua*). *Can. J. Fish. Aquat. Sci.* **2005**, *62*, 1104–1110.
25. Sumaila, U.R.; Cheung, W.; Dyck, A.; Gueye, K.; Huang, L.; Lam, V.; Pauly, D.; Srinivasan, T.; Swartz, W.; Zeller, D. Benefits of rebuilding global marine fisheries outweigh costs. *PLoS One* **2012**, *7*, e40542.
26. Clark, C.; Munro, G.; Sumaila, U.R. *Limits to the Privatization of Fishery Resources*; Working Paper # 2008–07; Fisheries Centre, University of British Columbia: Vancouver, Canada, 2008; p. 24.
27. Nakken, O.; Sanderbg, P.; Steinshamn, S.I. Reference points for optimal fish stock assessment: A lesson learned from the Northeast Artic cod stock. *Mar. Policy* **1996**, *20*, 447–462.
28. Yakubu, A.-A.; Li, J.; Conrad, J.M.; Zeeman, M.L. Constant proportion of harvest policies: dynamic implications in the Pacific halibut and Atlantic cod. *Math. Biosc.* **2011**, *232*, 66–77.
29. Froese, R.; Quaas, M. Mismanagement of the North Sea cod by the European Council. In Special issue on the Fisheries Policy Reform in the EU. *Ocean Coast. Manage* .**2012**, *70*, 54–58.
30. Lindegren, M.; Möllmann, C.; Nielsen, C.; Stenseth, N.C. Preventing the collapse of the Baltic cod stock through an ecosystem-based management approach. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 14722–14727.
31. Davies, R.W.D.; Rangeley, R. Banking on cod: Exploring economic incentives for recovering Grand Banks and North Sea cod fisheries. *Mar. Policy* **2010**, *34*, 92–98.
32. Standal, D.; Utne, I.G. Can cod farming affect cod fishing? A system evaluation of sustainability. *Mar. Policy* **2007**, *31*, 527–534.
33. Treasurer, J.; Atack, T.; Rolton, A.; Walton, J.; Bickerdike, R. Social, stocking density and dietary effects on the failure of farmed cod (*Gadus. morhua*). *Aquaculture* **2011**, *322–323*, 241–248.
34. Ovegärd, M.; Königson, S.; Persson, A.; Lunneryd, S.G. Size selective capture of Atlantic cod (*Gadus. morhua*) in floating pots. *Fish. Res.* **2011**, *107*, 239–344.
35. Diekert, F.K.; Hjermann, O.; Naevdal, E.; Stenseth, N.C. Non-cooperative exploitation of multi-cohort fisheries-The role of gear selectivity in the North-East Artic cod fishery. *Resour. Energy Econ.* **2010**, *32*, 78–92.
36. Da Rocha, J.M.; Cerviño, S.; Villasante, S. The Common Fisheries Policy: An enforcement problem. *Mar. Policy* **2012**, *36*, 1309–1314.
37. Eero, M.; Köster, F.W.; Vinther, M. Why is the Eastern Baltic cod recovering? *Mar. Policy* **2012**, *36*, 235–240.
38. Froese, R.; Branch, T.; Proels, A.; Quaas, M. Generic harvest control rules for European fisheries. *Fish. Fish.* **2011**, *12*, 340–351.
39. Froese, R. Fishery reform slips through the net. *Nature* **2011**, *475*, 7.
40. Froese, R.; Quaas, M. Three options for rebuilding the cod stock in the Eastern Baltic Sea. *Mar. Ecol. Prog. Ser.* **2011**, 434, 197–211.

41. Sea Around Us Project. Fisheries, ecosystem and biodiversity. Available online: http://www.seaaroundus.org/ (accessed on 22 February 2013).
42. Commission of the European Communities. *Green Paper-Reform of the Common Fisheries Policy*; Brussels, 22.4.2009; COM 163 final; European Commission: Brussels, Belgium, 2009.
43. Österblom, H.; Sissenwine, M.; Symes, D.; Kadin, M.; Daw, T.; Folke, C. Incentives, social-ecological feedbacks and European fisheries. *Mar. Policy* **2011**, *35*, 568–574.
44. Villasante, S.; Morato, T.; Rodríguez-González, D.; Antelo, M.; Österblom, H.; Watling, L.; Nouvian, C.; Gianni, M.; Macho, G. Sustainability of deep-sea fish species under the European Union Common Fisheries Policy. *Ocean Coast. Manage*. **2012**, *70*, 31–37.
45. International Council for the Exploration of the Sea (ICES). *Report of the ICES Advisory Committee*; ICES Advice 2011; ICES: Copenhagen, Denmark, 2011; Book 9, p. 148.
46. Costello, C.; Gaines, S.; Steven, D.; Lynham, J. Can catch shares prevent fisheries collapse? *Science* **2008**, *321*, 1678–1681.
47. Agnew, D.; Pearce, J.; Pramod, G.; Watson, R.; Beddington, J.R.; Pitcher, T.J. Estimating the worldwide extent of illegal fishing. *PloS One* **2009**, *4*, 45–70.
48. International Council for the Exploration of the Sea (ICES). ICES Report on Cod in Subarea IV (North. Sea) and Divisions VIId (Eastern Channel) and IIIa West. (Skagerrak). Available online: http://www.ices.dk/committe/acom/comwork/report/2012/2012/cod-347.pdf (accessed on 5 November 2012).
49. Ulrich, C.; Reeves, S.A.; Vermard, Y.; Holmes, S.J.; Vanhee, W. Reconciling single-species TACs in the North Sea demersal fisheries using the Fcube mixed-fisheries advice framework. *ICES J. Mar. Sci.* **2011**, *68*, 1535–1547.
50. Kraak, S.B.M.; Bailey, N.; Cardinale, M.; Darby, C.; de Oliveira, J.A.A.; Eero, M.; Graham, N.; Holmes, S.; Jakobsen, T.; Kempf, A.; *et al*. Lessons for fisheries management from the EU cod recovery plan. *Mar. Policy* **2013**, *37*, 200–213.
51. Folke, C.; Carpenter, S.; Walker, B.; Scheffer, M.; Elmqvist, T.; Gunderson, L.; Holling, C.S. Regime shifts, resilience, and biodiversity in ecosystem management. *Ann. Rev. Ecol. Evol. Syst.* **2004**, *35*, 557–581.
52. Villasante, S. The management of the blue whiting fishery as complex social-ecological system: The Galician case. *Mar. Policy* **2012**, *36*, 1301–1308.
53. Hutchings, J.A.; Swain, D.P.; Rowe, S.; Eddington, J.D.; Puvanendran, V.; Brown, J.A. Genetic variation in life-history reaction norms in a marine fish. *Proc. Roy. Soc. B Biol. Sci.* **2007**, *274*, 1693–1699.
54. Antelo, M.; Rodríguez-González, D.; Villasante, S. The Spanish fishing fleet and the economic value of Southern stock of European hake fishery (*Merluccius merluccius*). *Ocean Coast. Manage.* **2012**, *70*, 59–67.
55. Hilborn, R.; Walters, C. *Quantitative Fisheries Stock Assessment, Choice, Dynamics and Uncertainty*; Chapman and Hall: New York, NY, USA, 1992.
56. Froese, R.; Proelss, A. Rebuilding fish stocks no later than 2015: Will Europe meet the deadline? *Fish. Fish.* **2011**, *11*, 194–202.
57. Worm, B.; Hilborn, R.; Baum, J.A.; Branch, T.A.; Collie, J.S.; Costello, C.; Fogarty, M.J.; Fulton, E.A.; Hutchings, J.A.; Jennings, S.; *et al*. Rebuilding global fisheries. *Science* **2009**, *325*, 578–585.

58. Cottrel, A.; Lucchetti, R. Gnu Regression, Econometrics and Time-series Library (Gretl). Creation date 21 November 2012; Copyright © 2000–2012. Available online: http://gretl.sourceforge.net/ (accessed on 5 March 2013).
59. Sumaila, U.R. Intergenerational cost benefit analysis and marine ecosystem restoration. *Fish. Fish.* **2004**, *5*, 329–343.
60. Stern, R. *Stern Review on the Economics of Climate Change;* Her. Majesty's Treasury: London, UK, 2006; pp. IX, 579.
61. Weitzman, M. Gamma discounting. *Ame. EconRev.* **2001**, *91*, 260–271.
62. Walters, C.J.; Martell, J.D. *Fisheries Ecology and Management*; Princeton University Press: Princeton, NJ, USA, 2004.
63. Ruddle, K. Reconsidering the Contribution of Fisheries to Society and Millennium Development Goals. In *Fisheries for Global Welfare and Environment*, Proceedings of 5th World Fisheries Congress, Yokohama, 20–24 October 2008; Tsukamoto, K., Kawamura, T., Takeuchi, T., Beard, T.D., Jr., Kaiser, M.J., Eds.; Terrapub: Tokyo, Japan, 2008; pp. 399–411.
64. Ostrom, E.; Burger, J.; Field, C.B.; Norgaard, R.B.; Policansky, D. Revisiting the commons: Local lessons, global challenges. *Science* **1999**, *284*, 278–282.
65. International Council for the Exploration of the Sea (ICES). *Joint EU-Norway Request on the Evaluation of the Long-Term Management Plan for Cod*; ICES Special request Advice July; 2011; Book 6, pp. 6–16.
66. Walters, C.; Maguire, J.J. Lessons for stock assessment from the northern cod collapse. *Rev. Fish. Biol. Fish.* **1996**, *6*, 125–137.
67. Hardin, G. The Tragedy of the Commons. *Science* **162**, 1243–1248.
68. Cheung, W.L.; Lam, V.W.; Sarmiento, J.L.; Kearney, K.; Watson, R.; Pauly, D. Projecting global marine biodiversity impacts under climate change scenarios. *Fish. Fish.* **2009**, *10*, 235–251.
69. Garza-Gil, M.D.; Torralba-Cano, J.; Varela-Lafuente, M.M. Evaluating the economic effects of climate change on the European sardine fishery. *Reg. Environ. Change* **2011**, *11*, 87–95.
70. Voss, R.; Hinrichsen, H.H.; Quaas, M.F.; Schmidt, J.O.; Tahvonen, O. Temperature change and Baltic sprat: from observations to ecological–economic modelling. *ICES J. Mar. Sci.* **2011**, *68*, 1244–1256.
71. Arnason, R. Global warming: new challenges for the Common Fisheries Policy. *Ocean Coast. Manage.* **2012**, *70*, 4–9.
72. Folke, C.; Jansson, A.; Rockström, J.; Olsson, P.; Carpenter, S.; Crépin, A.-S.; Daily, G.; Ebbesson, D.; Elmqvist, T.; Galaz, V.; *et al*. Reconnecting to the biosphere. *AMBIO* **2011**, *40*, 719–738.
73. Ostrom, E. A general framework for analyzing sustainability of social-ecological systems. *Science* **2009**, 325, 419–422.
74. Chapin, F.S., III; Pickett, S.T.A.; Power, M.E.; Jackson, R.B.; Carter, D.M.; Duke, C. Earth stewardship: A strategy for social-ecological transformation to reverse planetary degradation. *J. Environ. Stud. Sci.* **2011**, *1*, 44–53.