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The Irish Orange Roughy Fishery: An Economic Analysis

Naomi Foley[†#], Tom van Rensburg[†]
Claire W. Armstrong[#]

Abstract

An Irish commercial fishery for orange roughy began in the Northeast Atlantic in 2001 with the assistance of government grants. The fishery began as an open access, non-quota fishery. The rapid boom and bust of many deep water fisheries was experienced. Landings peaked in 2002 and then dropped significantly the following year. Many vessels were forced out of the fishery due to high costs and rapidly declining stocks. By 2005 the fishery was largely closed. We present why the fishery no longer exists with a bioeconomic analysis and we discuss both the external and opportunity costs of the fishery. A bioeconomic model is applied to the available data to assess the open access effort and harvest with and without government grant aid. The results suggest that in the absence of subsidies, deep water trawling would not have been viable. In addition to the financial costs such as high fuel consumption, there are also externalities associated with a deep water trawling. Orange roughy is closely associated with deep water ecosystems such as seamounts and cold water corals. We discuss the costs of damage to cold water corals. These costs include the loss of fish habitats and lost future use and preservation values.

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1. Introduction

Increasing pressure on traditional fisheries in readily accessible inshore waters on the continental shelf has forced fishermen to explore deeper waters [1, 2]. These new fisheries are facilitated by the development of new fishing gear and sonar technologies. The move to deep water fisheries is encouraged further by governments offering grants and subsidies in an effort to alleviate the pressures on inshore stocks [3, 4].

Perhaps the best known example of the large-scale commercial exploitation of an underutilized deep water fishery is the case of the orange roughy (*Hoplostethus atlanticus*). Fishing for orange roughy began in Australia and New Zealand in the 1970s [5, 6] and subsequently in Namibia and Ireland in the 1990s [7, 8].

However, the orange roughy fishery is frequently cited as an example of poor fisheries management where the stock has declined significantly and is not rebuilding [9-11]. Orange roughy fisheries are also considered to be heavily subsidized [12], and involve excessive monitoring and compliance costs to the state [13, 14]. Concerns have also been voiced that the orange roughy fishery and its habitats are not resilient enough to withstand the destructive fishing practices on vulnerable deep sea ecosystems and the resulting environmental costs too large and uncertain to allow the fishery to continue [3].

On the other hand a number of other studies have argued that "the jury is still out on the question of whether orange roughy fisheries are sustainable over the long term [6, 15] and some suggest that the orange roughy fishery should continue and is both sustainable and economically viable [16], provides employment and supports coastal communities. Hilborn et al [16] report that the New Zealand orange roughy fishery was in fact sustainable and close to being economically optimal.

This inconsistent picture presents a number of difficulties for policy makers concerned about the management of the deep sea fishery. It is worth noting, however, that the paper by Hilborn et al [16] focuses on the fish stock and ignores the effects of fishing on the ecosystem and thus provides a financial perspective not an economic one since externalities are not given consideration. Concerns by academics and the public at large about the destructive effects of deep sea fishing are not confined only to the collapse of fish stocks as suggested by Hilborn et al [16] but have also focused on the negative external effects of trawling on deep sea habitats. Recently, attention has been drawn to the fact that deep sea habitats such as cold water corals and sea mounts play an important role in the provision of ecosystem goods and services. By damaging cold water coral, destructive fishing practices thus impose user costs[1] on the fishermen themselves but also other stakeholders. Glenn et al [18] report that the Irish public show strong preferences for a ban on trawling in order to conserve cold water corals in the Atlantic and Foley et al [19] suggest that fishing practices that damage cold water coral may reduce the yield of another deep sea fish species, redfish. Armstrong and van den Hove [20] also suggest that deep sea trawling can damage cold water coral and impose external effects on coastal fishermen.

An Irish fishery targeting orange roughy began in 2001 and ended shortly after, resulting in the boom and bust cycle of many orange roughy fisheries. Shephard et al [21] discuss the stakeholder aspects of the fishery and Minto and Nolan [22] have looked at the biological background of the fishery, while Shephard and Rogan have considered the seasonal distribution of the fishery [8]. There have been no discussions on the economics of the Irish orange roughy fishery.

In this paper we apply orange roughy data to a bioeconomic model and compare the results of the fishery with grant aid and without. Studies of orange roughy are limited, and we are only familiar with two studies applying a bioeconomic model to an orange roughy fishery, namely Hilborn et al [16] and Campbell et al [23]. Hilborn et al [16] use a simple model to evaluate alternative management histories for New Zealand orange roughy stocks. Campbell et al [23] use a cohort model to analyse the orange roughy fishery off the east coast of Tasmania, while we apply a biomass model. The short duration of the Irish orange roughy adventure, and the limitations in available Irish data make the application of a biomass model both acceptable and unavoidable. For the purposes of studying the economic consequences of this fishery, a biomass

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[1] Intertemporal scarcity imposes an opportunity cost that we refer to as the marginal user cost. When resources are scarce, greater current use reduces future opportunities. The marginal user cost is the present value of these forgone opportunities at the margin [17].

model is also sufficient. In this paper we provide an additional discussion compared to Campbell et al [23], namely of the externalities of fishing on deep water habitats associated with the orange roughy fishery and discuss whether the precautionary approach has a role to play in the fishery. The aims of this study are:

1. To describe the orange roughy fishery in the NE Atlantic.
2. To establish the influence of grant aid on the orange roughy fishery in the NE Atlantic.
3. To demonstrate why the NE Atlantic orange roughy fishery no longer exists.
4. To discuss the costs to the NE Atlantic orange roughy fishery including the external costs.

The remainder of this paper is as follows; the next section gives a background to the orange roughy fishery in Ireland and elsewhere. We then provide a brief description of the bioeconomic model and the orange roughy data set. We apply the data for the orange roughy fishery to the bioeconomic model and evaluate the open access harvest and effort with and without government grant aid. This is followed by a discussion on the additional costs to deep water fisheries including user costs, preservation values and the precautionary approach.

2. Background

2.1 Orange roughy

Orange roughy (*Hoplostethus atlanticus*) is a deep-water species, with an almost global distribution [15]. Orange roughy is associated with continental slopes and generally occurs at 200m to 1,800m, but is most commonly found between 700m and 1,400m where it is known to form spawning and feeding aggregations [15]. The species has a slow growth rate, is long lived (>100 years), has a low natural mortality, a high age-at-sexual maturity (25-30 years) and low fecundity [22, 24-29]. Orange roughy feeds on luminescent prawns, squid and fish [30].

Orange roughy was first fished commercially in 1978-79 from the Chatham Rise off New Zealand. Subsequently orange roughy fisheries have developed off south-eastern Australia in 1989 [31], in the northwest off the UK in the Rockall Trench off North west Europe and Ireland in 1990 [32], off Namibia in 1995 [33], in the Pacific off

Chile in 1998 [34], and most recently in the south western Indian ocean in 1999 [35]. Exploitation rapidly expanded to the East Indian Ocean when Australia became a major producer at the end of the 1980s, and to the Southeast Atlantic when Namibia joined the top producers in 1995. Orange roughy has become a popular export, with nearly half the catch going to the United States in 2001. All fishing for orange roughy is by bottom trawling.

New Zealand's orange roughy fisheries contribute over half of the global catch to date and approximately half of the annual catch in recent years [15]. In New Zealand, the orange roughy catch from seamounts grew from about 30% of the annual catch of orange roughy in 1985 to 80% of the annual catch by 1995, subsequently stabilizing at 60–70% [36]. Initially landings were maintained through the discovery of these new aggregation areas [6]. Reduced catches by the 1990s led to a search for new sites, and by 2000 approximately 80% of known seamounts had been fished [36].

Total global production of orange roughy peaked at 91,500 tonnes in 1990 but has sharply declined since, falling to some 25,000 tonnes in 2001, in part because New Zealand has set catch quotas. Namibia's catch reached 18,000 tonnes in 1997 and dropped by over 90 percent to 1,600 tonnes in 2000. Catches of newly discovered stocks often decline within a few years of their discovery, in some cases resulting in the closing of the fishing grounds.

The exact status of orange roughy stocks is difficult to determine due to a lack of accurate assessments for most stocks, the long lifespan of the species and the lack of information about pre-recruits [15]. Stocks often experience a rapid boom and bust cycle. Most orange roughy fisheries have been fished down within as little as 5-10 years to less than 20% of their original stock size. One recent analysis found that nearly half of 30 orange roughy stocks assessed had been fished below 30 percent of the original biomass of the stock [37]. In Namibia, orange roughy quotas fell from 12,000 tonnes to 1,875 tonnes as the stock was fished to less than 30% of its original biomass in 6 years [38, 39]. Koslow et al [40] and Clark [41] suggest that, even the Chatham rise, which is still actively fished has depleted a number of sub-populations and caution that the apparent longevity of the fishery, based on overall landings may be misleading.

In New Zealand the fishery of larger stocks has been successfully maintained, however for smaller stock sizes the fisheries are often unsustainable and unregulated fisheries may be especially vulnerable. For example Hilborn et al [16] suggest that most New Zealand orange roughy (*Hoplostethus atlanticus*) stocks are sustainably managed and can be cited as an example of successful, rather than failed, management. Hilborn et al [16] suggest that one could view the rapid decline in abundance of the orange roughy fishery as the fishery developed as a catastrophic collapse or, alternatively, as the planned development of a new fishery leading to near legislated outcomes. One of the reasons for this difference of interpretation is that for many orange roughy populations what we have witnessed over the last decade or two is “the fishdown phase” [39, 40]. Hilborn et al [16] suggests that part of the conflict in perceptions of the status of the orange roughy fishery comes from a focus on abundance as opposed to sustainable yield. After the “fishdown phase” fish stocks might be at relatively low abundance, indicating failed management to some, while still producing at or near MSY, indicating success to others. Hilborn et al [16] suggests that the case of orange roughy in New Zealand illustrates this distinction. Koslow et al [40] also suggest that large catches were taken off southeast Australia where catches peaked in 1990 at about 50,000 tonnes, and by 1996 were thought to be sustainable at a much-reduced 5,000 tonnes.

Unregulated stocks, small stocks as well as seamounts or sites where orange roughy is caught whilst forming feeding and spawning aggregations may be especially vulnerable. A study of the deep water stocks off the west of Scotland in 1994 suggested that “if the Atlantic stocks share the same biological characteristics of slow growth and low reproductive potential as those of the South Pacific then the prospects of a high-yield, sustainable fishery would appear to be poor” [42].

In some instances where the fishery is unregulated, stocks have been fished to commercial extinction. Orange roughy has been the subject of aggregation fishing at the tops of seamounts off New Zealand, Australia, and Namibia for a number of years. In their review of aggregation fisheries Sadovy and Domier [11] conclude that aggregation-fisheries are likely to be sustainable only for limited subsistence-level use.

In two papers that focussed on sustainability of orange roughy stocks Francis and Clark [15] and Clark [6] concluded that it is still unclear whether the orange roughy is sustainable over the long-term.

2.2 The Irish Orange Roughy Fishery

In the NE Atlantic orange roughy do not appear to form the large aggregations found in the Southern Hemisphere [8]. Orange roughy spawn between January and April with peak spawning occurring between late February and early March [8].

Prior to 1999, Irish landings of deep-water, non-quota species were very limited due to the lack of suitable vessels greater than 24m overall length and 1000hp in the fleet [43]. Large high-sea French trawlers targeted orange roughy in ICES area VII from the late 1980s. By the end of 2000 the French fleet had removed over 13,500 tonnes from this subarea [44].

In 2000 a programme to develop an Irish deepwater fishery began in ICES area VII with the support of grant aid from the *Whitefish Renewal Programme* [21]. The programme saw the introduction of 29 new vessels, 16 of which were between 16 and 46 meters in length to allow Irish fishermen to compete on equal terms in offshore fishing grounds [45]. Levels of capital grant aid provided under the programme included up to 40% of the eligible costs of new vessels [43]. Conditions of the grant aid included specification that a percentage of target species should be non-quota.

The exploratory fisheries were run with Irish Sea Fisheries Board (BIM) and some commercial fishermen. Of the deep water species harvested during the exploratory period, orange roughy fisheries appeared to be the most valuable and offer the largest returns [43].

The fishery experienced the rapid boom and bust cycle familiar to many deep-water fisheries. Landings data suggests pulse landings; the first occurred in 1992 when over 3,000t were landed and the second in 2002 [46]. In 2003, a total allowable catch (TAC) of 1,349 tonnes was set on the orange roughy fishery in ICES area VII, of which Ireland received 300 tonnes [21]. The quotas were not well received by the

Irish fishermen who felt they had invested in non-quota fishery and were only beginning to recoup the costs of their exploratory investment [21].

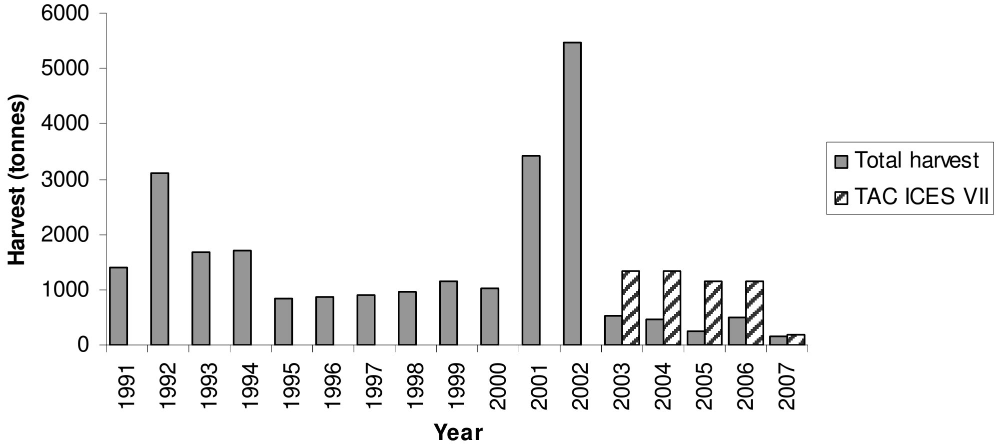

Figure 1: Orange roughy harvest ICES VII 1991 – 2007

In addition to a rapid drop in landings, fuel prices increased during the short period of the fishery and the average prices per tonne dropped. The large fuel consumption of deep water trawling makes these vessels extremely sensitive to fuel price increases [4, 47]. Landings declined markedly in 2003 and 2004, as shown in **Error! Reference source not found.** with several vessels being forced out of the fishery [8]. In 2001 the average price per tonne was at its highest at €3,138 but by 2003 price had dropped 41% to €1,285 per tonne. Mellett [48] reports that the market was flooded and with the price collapse large quantities of orange roughy were sold for fishmeal. All this resulted in several vessels being forced out of the fishery [21].

2.3 The financial significance of the Irish deep water sector

According to statistics from the Sea Fisheries Protection Authority (SFPA) orange roughy was ranked tenth in the top ten species by value in Ireland in 2001. In subsequent years orange roughy did not feature in the top 10. Figure 2 illustrates the annual monetary value of landings for each fishery sector; pelagic, shellfish, demersal and deep water. At its peak in 2002 the deep water fishery accounted for 7.65% of landings value, after which it continued to decline and by 2006 it accounted for 1% of landings value.

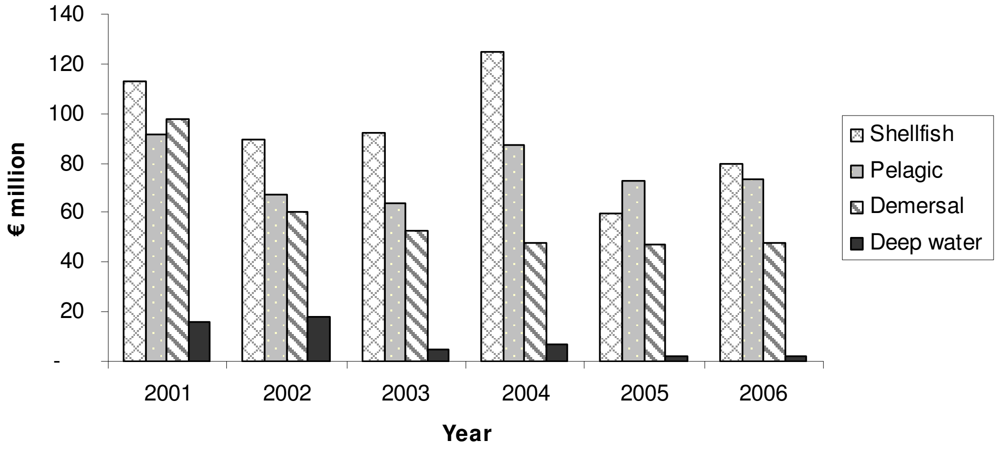

Figure 2: Fishery Sector Value (million euro). Data source: SFPA

2.4 Deep water fisheries and subsidies

There is a growing literature on subsidies and fisheries [49, 50]. The Irish orange roughy fishery began with the assistance of government grant aid to update or purchase vessels. Khan et al [51] identified twelve types of subsidies and categorised state support into three different groups; *good, bad* and *ugly.* Among the subsidies listed were boat construction, renewal and modernisation which were categorised as *bad* subsidies. *Bad* subsidies are defined by Khan et al [51] as subsidy programmes that lead to disinvestment in natural capital assets once the fishing capacity develops to a point where resource exploitation exceeds the Maximum Economic Yield (MEY).

Many argue that global deep sea fishing could not be possible without subsidies [4, 49, 52]. Bottom trawlers operating in the deep sea consume large volumes of fuel, which is subsidized by the state in many areas of the world. A recent study by Sumaila et al [4] estimates the global fuel subsidies given to high seas bottom trawlers which target deep sea species such as orange roughy. It was found that bottom trawlers are not highly profitable, that they only contribute a small percentage to global fish catch and landed values. They conclude that in the absence of fuel subsidies to these bottom trawlers, deep sea fishing would not take place. Sumaila and Pauly [50] demonstrated that the amount of subsidies received by deep sea bottom trawlers is greater than the likely profits that they generate.

3. Bioeconomics

In this section we apply a simple bioeconomic model to available data on the orange roughy fishery. Following such a short-lived fishery and the suspected misreporting of catches following the introduction of the TACs [8], there is a lack of data for this fishery. Nonetheless, with the available data it is possible to apply a standard Gordon Schaefer model to the data. We consider two cases using bioeconomic analysis. In the first case we consider the fishery as it was i.e. with the subsidy included in the total costs. In the second case we remove the subsidy from the model and analyse the change in open access conditions. A discussion will follow on the additional costs of the fishery, specifically the cost of habitat loss.

Bioeconomic modelling is a well established approach that uses mathematical techniques to model the performance of 'living' production systems subject to economic, biological and technical constrains [53]. Bioeconomic models integrate biological and physical systems and relate them to economic considerations, which include market prices, resource allocation and institutional constraints (Cacho 2000). These models combine ecological and economic models to analyse human interaction with nature [54].

3.1 The Model

Ideally, when studying a slow growing, long lived species such as orange roughy we should apply a cohort model. However, the data indicates that the Irish orange roughy stock has been mined over the few years it has been exploited. This and the fact that biological data on the stock is very limited justify the application of a standard bioeconomic biomass model where the population dynamics are described by;

$$\frac{dX}{dt} = F(X) - h \qquad (1)$$

where $F(X)$ is the natural growth rate of the stock and h is the harvest. The growth curve commonly used in the Gordon-Schaefer model is the logistic growth equation;

$$F(X) = rX(1 - \frac{X}{K}) \qquad (2)$$

where r is the intrinsic growth rate of the stock and K is the carrying capacity which is the size the stock will approach in the absence of harvesting. The short term harvest is given as

$$h = qEX \qquad (3)$$

where q is the catchability coefficient and E denotes effort. Assuming equilibrium we obtain the equilibrium harvest equation which can be inserted into the profit function of the fishery:

$$\pi(E) = TR(E) - TC(E) = p \cdot h(E) - c \cdot E \qquad (4)$$

where TR is the total revenue from the fishery, TC are the total costs, h represents the equilibrium harvest and E is the unit of effort. Unit price of harvest (p) and unit cost of effort (c) are assumed constant.

As mentioned above, grant aid was given for the purchase of new vessels, as there are large costs[2] associated with deep water fisheries and orange roughy is closely associated with deep water habitats. Therefore, in this study there are two possibilities to consider with regard the cost function.

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[2] A study of the deep water stocks off the west of Scotland in 1994 suggested that any vessels taking part in the deep water fishery for orange roughy will require high levels of investment in powerful winches, sophisticated echo sounders and net monitors and would probably experience a high cost in gear damage [42]. In the case of Scotland, the report questioned whether such an investment would be justified for a fishery which seems to have little chance of being effectively managed in the near future.

The standard cost function is:

$$TC = cE \qquad (5)$$

If a subsidy is given as an annual cost reduction, the costs (c) are reduced by the amount of the subsidy (s)

$$TC = -s + cE \qquad (5^*)$$

In the analysis that follows we present the effort, harvest and stock sizes for the static maximum sustainable yield (MSY) solution, the open access (OA) solution with and without the subsidy and the long run optimal yield (OY). In open access effort reaches equilibrium (bionomic equilibrium) where total revenues equal total costs yields zero resource rents. Solving this equation for the open access stock size without a subsidy is standard. Solving the zero profit function with a fixed subsidy (5*) yields a quadratic equation in *X*, which can then be solved for the open access stock size with a subsidy. If the fishery were managed by a sole owner, their aim is to maximise the long run present value of the stream of resource rent:

$$MaxPV(\pi)\int_{0}^{\infty}(p - c(x))he^{\delta t}dt \qquad (6)$$

where δ is the discount rate and $c(x) = \frac{c}{qx}$ is the unit harvesting cost. Applying the data below, we assess the orange roughy fishery according to the reference points that the different management scenarios give.

3.2 Data

To conduct the bioeconomic analysis, harvest data, effort data, values for costs and revenues, and biological parameters are required. Table 1 summarises the bioeconomic parameters. Harvest data was obtained from ICES reports [44]. Data on effort is based on number of days at sea for trawlers targeting orange roughy.

Cost data are estimated from the BIM report [43] on the deep water fishery which supplies profit and loss accounts for the year 2001. The report estimates that for 50 days of fishing the total expenses are €546,174, of which €58,082 are vessel repayment costs. The costs in this report are less the grant aid of 40% for vessel repayments. This makes the daily cost without the subsidy equal to €11,696, and with the subsidy the cost comes to €10,923. Prices were obtained from the Central Statistics Office (CSO) database. Price is the average price per tonne over the period 2000 – 2005.

The catchability coefficient is calculated as $q = \frac{CPUE}{x}$ using 2001 data. Basson et al [55] calculated the carrying capacity for ICES VI using a logistic growth function. Due to a lack of data they were unable to calculate the same for ICES VII. In this study a similar problem arose. Comparing the estimate by Basson et al [55] for the carrying capacity with the total harvest in ICES VI, it was found that total harvest was very close to *K*. This makes sense because the stock was fished down. An estimate for carrying capacity in our case is obtained by summing the total harvest for ICES VII and adding 10% to error on the side of caution[3]. The intrinsic growth rate is set at 0.025 as described by Clark et al [56].

Effort data was sourced from the Marine Institute and the SFPA. Effort is *number of fishing days* for the years 2001-2005.

Table 1. Parameter values applied to the bioeconomic model

Parameter	Value
r	.025
K	30,000 tonnes
q	.0002 per day at sea
p	€1,890 per tonne
c (with subsidy)	€10,923 per fishing day
c (without subsidy)	€11,696 per fishing day
δ	5%

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[3] We thank Sam Shepherd at the Galway Mayo Institute of Technology (GMIT) for this suggestion for estimating the carrying capacity.

3.3 Analysis

Table 2 shows the open access and maximum sustainable yield (MSY) reference points for the Gordon-Schaefer static analysis. In addition the long run optimal yield is presented, maximizing the present value of the fishery. In the case of the Irish orange roughy, the open access harvest is less than MSY. When grant aid is not provided for vessel repayments open access and MEY values become negative i.e. there would be no fishery.

Table 2: Reference points (equilibrium effort, harvest and stock) for maximum sustainable yield (MSY), open access (OA) and long run optimal yield (OY), given the parameter values in Table 1 . Subscript *s* stands for the inclusion of subsidies.

	MSY	***OA***	***OA_s***	***OY***
E **(number of days fishing)**	62	0	5	0
h ***(*****tonnes)**	187	0	27	0
X (tonnes)	15,000	30,000	28,897	30,000

It can be seen from Table 2 that the costs are so high, even for the subsidized case, that even subsidised open access harvest become very small, indeed less than 15% of the equivalent MSY levels. In essence an equilibrium fishery at the MSY level would only require one or two vessels fishing in the peak season. However, due to the high costs relative to the average price level, it does not pay for any vessels to take part in a *sustainable* orange roughy fishery. It is hard to immediately understand why there was an orange roughy fishery at one point. Here we must remember that at its peak, the price was €3,138 per tonne. As the model is highly sensitive to price, this somewhat less than doubling of the price leads to a more than tenfold increase in equilibrium open access effort, and makes the long run optimal annual harvest level close to the MSY. This explains the initial interest in the harvesting of orange roughy. However, the differences between the subsidised costs and the non-subsidised costs are relatively small, and it seems clear that the fishery could have commenced without subsidies.

According to Table 2 we see that number of days that any of the equilibrium scenarios suggest do not come close to recommending the large number of vessels that actually entered the subsidised fishery. Hence it seems clear that the fishery was not at all in equilibrium, but that the stock was being mined. This is clear when comparing the MSY of about 260 tonnes with the actual total harvest described in Figure 1. Hence the subsidies did not encourage an equilibrium harvest, but rather the mining of the orange roughy stock. For a fish stock with a low growth rate relative to the market discount rate, there is the incentive to mine the stock and invest the profits in other sectors [50]. It is better, according to capital theory, to harvest the stock and invest it in a sector that offers a higher a rate of return.

4. Discussion

In this paper we described the rise and fall of the Irish orange roughy fishery. The fishery began in 2001 following deep water exploratory trials in 2000 but ended a short number of years later because of high fuel costs, low prices, low TAC shares, rapidly declining stocks and sustainability issues [57]. During the short period of the fishery harvests reached a peak in 2002 and then dropped by 75% the following year; fuel prices increased; price per tonne dropped; and when TACs were introduced by the EU, Ireland only received 300 tonnes.

There is a growing literature on the global impacts of subsidies to fisheries in general and more specifically to deep water and high seas fisheries [4, 12, 50]. Through the *Whitefish Renewal Scheme* grant aid was offered to Irish fishermen for the updating or purchase of new vessels, an incentive was given to enter into the deep water fishery and diversify from shallower waters. The results of our bioeconomic analysis are interesting for two reasons (1) our calculated open access effort and harvest are significantly lower than the estimated MSY levels, i.e. the costs are so high that even under open access, the effort is low, and (2) through our analysis we have shown that even in the presence of grant aid total costs would have been too high for a sustainable fishery of any size to take place. In essence the government's grant aid was a subsidy for mining the Irish orange roughy stock. The analysis with no subsidy suggests that on average the costs were too high, and the prices too low to support entry into the fishery. This supports the work of Sumaila et al [4] who claim subsidies to be the Achilles heel of deep sea trawl fleets, albeit that they discuss fuel subsidies.

There is a broader question as to whether orange roughy fisheries are sustainable in an economic sense, and this issue has received scant attention in the literature. All of the literature on the sustainability of orange roughy fisheries investigates this question from a narrow single species perspective based only on the orange roughy stock and concludes that it is still unclear whether orange roughy fisheries are sustainable [6, 15, 16]. In what follows we explore this issue from a broader economic perspective and take a clear position on this question for the Irish orange roughy fishery.

Economic theory suggests that a key condition of weak sustainability is that a) the aggregate capital stock should be non-declining [58] and, b) that the rents from a renewable resource that is depleted should be reinvested in other forms of capital. An important condition of strong sustainability is that natural capital itself should be non-declining [59, 60].

With respect to the weak sustainability condition, the Irish orange roughy fishery is an open access fishery, consequently rents are presumably dissipated, there are no rents to reinvest and rents have never been collected by the Irish exchequer for this fishery. With regards to the second criteria there is growing evidence that the natural capital stock both in terms of the orange roughy population and cold water coral (CWC) habitats are declining. The Irish roughy fishery fails to meet both these sustainability criteria and therefore from an economic standpoint it cannot be argued that it is a sustainable fishery.

It is worth noting also that not only did the public exchequer fail to collect the rents but that the public exchequer actually used tax payers' money and bore a lot of the costs in the form of subsidies to establish the fishery in the first place.

A final aim of this paper was to evaluate the costs to the N. East Atlantic orange roughy fishery including the external costs. Although we do not address this question empirically we are of the view that it is worthy of comment in view of the external benefits associated with orange roughy habitat. Managers must balance the benefits of the fishery, for example food, income and employment, against the costs of fishing impacts [61]. It is critical that all impacts are taken into account to ensure that the current gain from the fishing activity is not at the expense of significant reductions in other environmental functions, now or in the future [61]. This brings us to the additional cost of harvesting species such as orange roughy, namely the potential loss of deep water habitats such as cold water corals which can be considered a negative externality caused by the trawling industry. Deep sea trawling is thought to represent the single biggest threat to CWC ecosystems which are slow growing, fragile and vulnerable to deep-water fisheries [62-64]. This also puts at risk their potential alternative use to humans [65].

The external costs of deep water trawling include the loss of spawning grounds and the amenity value associated with CWC habitat. For example Armstrong and van den Hove [20] show that coastal fishermen are of the view that CWC areas function as natural marine reserves for fish and thus the corals are valuable in maintaining their fishery. As bottom trawling expands its reach into steadily deeper waters, CWC reefs are getting increasingly damaged. Foley et al [19] applied a production function approach to reveal that a decline in CWC habitat of between 30% and 50% could explain a drop in the harvest of Norwegian redfish of between 11% and 29%. Hence despite fisheries increasingly being managed, the commons nature of fish habitats may be resulting in the classical tragedy.

Amenity values such as existence values for CWC may also be significant. Glenn et al [18] used choice experiments to elicit public preferences for the protection of CWC in Ireland. Although a precise monetary value could not be placed on the resource, results indicate strong preferences for a ban on all areas where CWC are thought to exist and findings suggest that a large percentage of those surveyed valued corals, would like to see them protected for future generations, for their role as an essential fish habitat (EFH), for their pure existence value and also for the option to use or see them in the future.

These concerns about habitat damage are not restricted to Ireland. Studies in Norway [62, 66], the United States [67], Chile [68-71], Australia [72] and New Zealand [73] have also voiced similar concerns. It has been estimated that between one third and a half of known deep-water coral habitat in Norwegian waters has already been impacted by trawling.

The problem is that the social costs of damaging CWC habitat are typically borne by others, sometimes at considerable distances from the trawling activities. A further problem is that CWC and seamount habitats and to some extent the orange roughy fishery itself are essentially exhaustible resources, at least when seen from an ecological viewpoint. Their destruction may imply the disapeareance of ecosystems that have evolved over thousands of years. These CWC and seamount habitats harbour a rich diversity of flora and fauna, only a small fraction of which scientists have properly investigated because scientific enquiry in the deep sea cannot keep abreast of fishing activities [74]. A difficulty in relation with decisions of this type arises because of uncertainty in future valuations of CWC ecosystem services. We know from the literature of optimal harvest decisions in relation to old growth forests that the presence of non-market amenity values provided by a standing forest has an important impact on when or indeed whether to harvest [75, 76]. d' Autume and Schubert [77] have shown that the resource stock of an exhaustible resource remains for ever higher when it has amenity value and Conrad [75] and Reed [78] demonstrated that if the value of non-market amenities is high enough it may never be optimal to cut an old growth forest for its timber.

In conclusion our findings suggest that deep sea trawling in Ireland for orange roughy contributes very little with respect to net social benefits (profit and/or employment), and has not been economically sustainable. Though mining of orange roughy can be defended on capital theoretic terms, when resource rent is optimally taxed and reinvested, the trawling after orange roughy can be expected to impose significant external effects in terms of future user costs to the fishery as well as heritage and existence values [18].

For a fishery such as orange roughy, where biological and stock data is limited and where the external costs have yet to be itemised and valued a precautionary approach is well advised. The policy of taking action before uncertainty about possible environmental damages is resolved has been referred to as the 'precautionary principle'. One justification for this is that the costs of damage to biological resources may exceed the costs of preventative action [79]. Also, as seen irreversible damage may occur, such as species extinctions. The emphasis is thus on avoiding potentially damaging situations in the face of uncertainty over future outcomes [80, 81]. The precautionary principle could also be implemented by using marine reserves as a part of fisheries management [82].

In 2005, the Irish marine authorities took a decision to impose a temporary ban on fishing for orange roughy thus pursuing a precautionary approach in the absence of information of a more detailed scientific and economic nature. Our findings indicate that this was a move in the right direction.

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