RESEARCH ARTICLE

Disaggregating species unit costs in mixed fisheries: the case of the Irish whitefish fleet

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Received 16 November 2020 / Accepted 3 May 2021

Handling Editor: Dr. Olivier Thebaud

Abstract – Many fishing fleets operate in mixed fisheries where several target species are caught together along with other bycatch species unintentionally caught. In some cases, fleets operate in multiple mixed fisheries depending on various factors such as time of year or current market conditions, among other factors. Data collection in the European Union (EU) involves various levels of detailed data. Economic data is generally collected on an annual time-step whereas other sources provide information at much higher resolution such as the fishing trip (landings declarations), fish day (logbook) or even in real-time (electronic logbook). In this paper a methodology is described to disaggregate the annual cost of a fleet segment into a cost per fishery and per species within the fishery. This information is of interest as it permits incorporation of the economic implications of fishery dynamics into fisheries management. Assessment of these unit costs on a fishery basis also allows accurate input into value chain analysis which is carried out on a species basis.

Keywords: Unit costs / disaggregation / mixed fisheries

1 Introduction

The objective of this study is to develop a methodology to estimate the total cost involved in landing one unit (e.g., 1 kg) of a selected species of fish. This is of interest from a fleet management perspective as the result can be used to assess the economic performance of fishing fleet operations when used in combination with the price. In general, a unit cost per species of below the unit price of said species shows that there is, at a minimum, normal marginal profits being generated by the fleet in capturing this fish. Depending on the variety of fishing fleet segments¹ capturing a species the unit cost for each may vary, along with the unit price and so the difference in profit or loss margins can indicate which segments are the most efficient or profitable in capturing said species. Therefore, from a manager's perspective, knowledge of unit costs of species between fisheries may assist in the allocation of valuable quota at the national level where certain fisheries could face the problem of early closures due to the presence of choke species. From a market perspective the unit cost of capturing a species is of interest in assessing the supply chain and assessing

potential opportunities for value added activity. Knowing the margin gained by the fishing sector compared to other sectors such as processors, wholesalers and retailers is of interest when assessing the supply chain. This has social consequences with regard to the distribution of benefits along the value chain and can reflect the power dynamics, for example between large retailers as price setters and fishers as price takers.

To estimate cost per unit of landings of a species first the total costs of the group of vessels landing the species must be assessed. The economic performance of EU fleets are estimated annually through the Data Collection Framework (DCF) by means of economic surveys of active fishers (Council of the European Union 2009; 2017). The results of these surveys carried out across EU member states' fishing fleets describe the cost breakdown by fleet segments² across the EU and feed into the Annual Economic Report of EU fishing fleets each year³. These fleet segments are formulated based on the volume share of landings of each vessel by each fishing gear. For example, if over half of the volume of fish landed by a vessel was with the use of demersal trawls or seines then the vessel is classified as a 'DTS' (demersal trawl and seine) fleet segment. A fishery has been defined as a group of

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¹ Defined as a group of vessels with the same length class and predominant fishing gear during the year (Commission Decision (EC) No 949/2008).

² Defined under common criteria to allow comparability across EU fishing fleets.

³ <https://stecf.jrc.ec.europa.eu/reports/economic>.

vessel voyages targeting the same assemblage of species and/or stocks, using similar gear, during the same area and within the same part of the year (Davie and Lordan, 2009). As many fleets are active in multiple fisheries, some of which are mixed, economic analysis has been focused on the fleet segment. This is understandable from the point of view of collection of data however it may be problematic as the results may hide unprofitable fisheries. In order to effectively measure the relative economic performance of alternative fishing fleet segments, according to the fisheries in which they operate, the annual costs estimated for the Annual Economic Report must be disaggregated to the level of cost per landed unit of the species in question.

Many studies have assessed economic performance of fishing fleets using indicators based on data from data collection systems such as the DCF. The problem of scaling occurs in the DCF due to the homogenous criteria applied across all member states (Simmonds et al., 2011). Scaling issues occur in areas such as small-scale fleet definition (Carvalho et al., 2011; Guyader et al., 2013), crew share remuneration (Guillen et al., 2015; Prellezo and Iriando, 2016), profitability measurement (Boncoeur et al., 2000; Garza-Gil et al., 2011) among other areas. (Daurès et al., 2013) proposed a range of predictive models of operational costs to overcome a number of problems with the DCF economic programme such as difficulty in gathering survey data, incomplete coverage of fleets and inadequate coverage of fisheries. The cost structure models parameterised explain the drivers behind each cost aspect and in certain cases allow application to data deficient fleet segments. Garza-Gil et al. (2011) assessed the profitability of the Spanish purse seiner fleet after a structural change using bootstrap techniques. Boncoeur et al. (2000) propose an alternative measure of long-term profitability for small-scale fleets as the indicators in use were not detecting structural changes in fleets in the English Channel. Guillen et al. (2015) analyse how the crew share remuneration system affects rent distribution and fishing decisions.

In this paper an attempt is made to re-scale the DCF fleet-based data to the level of the fishery. DCF data collates economic data on EU fishing vessels and aggregates this into fleet segments. The methodology here will take into account the fisheries that a species occurs in and then allow estimation of the unit cost of landing said species (see Fig. 1 for a map of fishing grounds around Ireland). The methodology will be applied to two species of importance to the Irish seafood sector, hake and nephrops, for illustrative purposes. These species are selected as they are key target species for a number of fleet segments in Ireland and largely influence their economic performances. An interesting aspect of fisheries is that certain species can be caught in different fisheries and so the costs involved in landing different species can differ depending on the fisheries in which these species occur. For example, whiting can be caught in a targeted whiting fishery while it can also be caught as a bycatch species in a targeted fishery for another species such as nephrops. Hence, a unit cost of fishing each species is dependent on the fishery in which it is caught.

The fleets that target hake and nephrops and the relevant fisheries will be described in the background section. The methodology will then be described in the materials and methods section. Results will then be detailed followed by a discussion and conclusions.

2 Background

Hake and nephrops are landed mainly by the polyvalent general fleet, the largest segment of the Irish fleet with the most vessels, gross tonnage and vessel power. Irish national segmentation is more broadly defined than DCF segmentation⁴ and is based on the potential fisheries that a vessel can exploit⁵. The polyvalent general segment mostly use demersal trawls but can also use gillnets and other assorted gears. The segment lands a multitude of whitefish species (over 70) in varying quantities. The segment includes vessels that range from small inshore vessels below 10 m in length to offshore vessels above 30 m with the vessel length (VL) classes above 18 m accounting for the majority of landings of the main species. The three main targeted mixed fisheries that this segment exploits have been identified as the nephrops fishery⁶, the hake-monkfish-megrim fishery⁷ and the cod-haddock-whiting fishery⁸.

The nephrops (NEP) fishery in Ireland occurs across numerous functional units (fishing grounds) in the Irish Sea and in the Celtic Sea⁹. The vessels that exploit this fishery are mainly trawlers utilising nets with 70–80 mm mesh size codends. The fishing grounds, technical characteristics of the vessels and other factors determine the level of bycatch in this fishery which can include whiting, haddock, cod and other whitefish species.

The hake-monkfish-megrim (HMM) fishery generally occurs on a north-south line to the west of the island of Ireland corresponding to increasing water depths along the continental shelf of Ireland. Vessels exploiting this fishery are mainly trawlers utilising nets with 100–120 mm mesh size codends.

The cod-haddock-whiting (CHW) fishery occurs throughout the Celtic Sea by trawlers utilising nets with 100–120 mm mesh size codends.

In Figure 2 below the value of declared landings of hake and nephrops are shown for the main segments of the Irish fleet. It can be seen that the polyvalent general segments of

⁴ DCF segmentation is determined by the volume of fish landed by the predominant gear. See <https://datacollection.jrc.ec.europa.eu/wordef/fleet-segment-dcf> and Commission Implementing Decision (EU) 2016/1251 for further details.

⁵ The main segments in Ireland are pelagic, beamer, specific, polyvalent general and aquaculture. The corresponding DCF segments are broadly pelagic trawl (TM), beam trawl (TBB), dredgers (DRB), demersal trawls and seines (DTS) respectively (excluding aquaculture). Further details can be found here; <https://www.gov.ie/en/organisation-information/5907a-sea-fisheries-administration/>.

⁶ Browne et al. (2017).

⁷ Also known as benthic fisheries; ICES Fisheries Overviews; Celtic Seas Ecoregion (2020).

⁸ Also known as gadoid fisheries; ICES Stock Annex: Celtic Sea Mixed Fisheries Annex (2015).

⁹ Six functional units of nephrops are exploited by the Irish fleet namely FU 15–Irish Sea, FU 22–the Smalls, FU 20–21–Labadie, Jones and Cockburn, FU 19–Ireland SW and SE coast, FU 17–Aran, Galway Bay and Slyne Head, FU 19 Porcupine Bank. <http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2018/2018/nep.fu.14.pdf>.

Fig. 1. Important fishing grounds around Ireland; source BIM Inshore Fishery GIS Viewer.

Fig. 2. Value shares of total Irish hake and nephrops landings by fleet segment in 2019 (see Tab. A.1 in Appendix).

VL1824 and VL2440 (hereafter grouped and labelled the ‘whitefish fleet’) account for 85% of the value generated from total Irish hake landings and 94% of the value of total Irish nephrops landings. Given this dominant position focus will be drawn upon the cost structure of the whitefish fleet to associate costs to these species.

3 Materials and methods I: fishery allocation

As mentioned previously the Irish whitefish fleet generally operates in the three main fisheries of CHW, HMM and NEP. Other fisheries are exploited by this fleet at certain times of the

Table 1. Summary statistics for the whitefish fleet by fishery.

	CHW	HMM	NEP	OTH	Total
Effort (Days at Sea)	2598	8374	11 074	3760	25 807
Landings (Tonnes)	5 411 951	9 757 407	7 853 700	34 339 555	57 362 614
Revenue (€)	12 404 401	32 150 455	61 994 331	37 247 203	143 796 390
Price (€/KG)	2.29	3.29	7.89	1.08	2.51

Fishery definition: (cod, haddock, whiting – CHW; hake, monkfish, megrim – HMM; nephrops – NEP; all others – OTH).

year such as the spring herring fishery, the mackerel fishery or the albacore fishery during the late summer months. Therefore, a fourth fishery encompassing these and any other fisheries will be assigned to the fleet (OTH).

Why a fisher makes a decision to enter a fishery is due to a number of reasons spanning their capabilities, the technical capacity of their vessel, regulatory constraints and the potential economic returns among other factors. From an economic perspective the potential economic returns from fishing something somewhere is the main driver affecting fishery choice and fisher behaviour. Fisheries where an operator can make a higher profit will be favoured and effort within that fishery should increase (Hilborn, 2007).

Part one of the methodology is to assess the activity of the fleet by fishery. Here this is done by analysis of detailed logbook data. Detailed data analysis at the level of the trip is required as summarised data at greater temporal scales (month, year) may include activity in various fisheries. EU logbooks¹⁰ are composed of a daily sheet recording the catch details (including volume, area and gear used) per day with a landings declarations sheet that is filled out at the end of the trip in the port summarising total landings per species and area (ICES sub-division) for the entire fishing trip¹¹.

Analysis of logbook databases allows assessment at the level of the fishing day while analysis of landings declarations databases allows assessment at the level of the fishing trip. For the purposes of examining activity within fisheries, assessment of landings declarations is sufficient as the majority of fishing trips are expected to be in a distinct fishery rather than multiple fisheries being exploited within one fishing trip, given the length of time involved in rigging the distinct gear specifications on board the vessel across fisheries. The value of each species landed is incorporated into the landings declarations database through linkage with the sales notes database. Sales notes, collected across the EU, are submitted by the buyer or the seller at the first sale of fish and show information on the freshness, presentation and size grade by species.

For the purpose of this exercise each fishing trip must be assigned to one of the selected fisheries. For each trip landings of cod, haddock, whiting, hake, monkfish, megrim and nephrops were assessed in terms of volume and value, with a grouping of other species summing up all other species landed from the trip. The economic value of cod plus haddock plus whiting composed the CHW value, the value of hake,

Whitefish Fleet Fishery Characteristics

Fig. 3. Effort (days at sea), landings (tonnes) and revenue (€) shares of the whitefish fleet by fishery (cod, haddock, whiting – CHW; hake, monkfish, megrim – HMM; nephrops – NEP; all others – OTH) in 2019.

monkfish and megrim composed the HMM value and the nephrops value composed the NEP value. All other species were summed to compose the OTH value. The trip was then allocated to the grouping of whichever of the four economic values was largest. For the set of all fisheries $F = \{f_1, \dots, f_k\}$ the determination of fishing trip into a fishery will follow;

$$\text{Fishing Trip}_F = \max \{ \text{Value}_{f_1}, \text{Value}_{f_2}, \text{Value}_{f_3}, \dots, \text{Value}_{f_k} \}$$

where Fishing Trip_F is the fishery of the fishing trip, Value_{f₁} is the value of all fish landed within fishery 1 of the fishing trip, Value_{f_k} is the value of all fish landed in fishery k of the fishing trip, and the fishery of maximum value determines Fishing Trip_F.

This method follows the logic that fishers fish for value and not quantity of fish (Grafton et al., 2006; Hilborn et al., 2004). The data used in this exercise relate to the year 2019.

Basic statistics on activity of the fleet per fishery showing the distribution of effort, volume of landings and value of landing are shown in Table 1. With this information the disaggregation of costs to a fishery can begin.

Figure 3 presents the allocation for the whitefish fleet of total effort applied, total landings and total revenue within each of the four fisheries considered (cod-haddock-whiting – CHW, hake-monkfish-megrim – HMM, nephrops – NEP and other – OTH). The NEP fishery is the most exploited accounting for around half of all effort, followed by the HMM fishery with around 25% of total effort. The remaining quarter of effort is shared between the CHW and OTH fisheries. In terms of landing volumes the OTH fishery dominates with

¹⁰ http://www.bim.ie/media/bim/content/BIM_USERFRIENDLY-GUIDE_EU_LOGBOOK_SECTION1.pdf.

¹¹ https://ec.europa.eu/fisheries/cfp/control/technologies_en.

Table 2. Number of vessels of the whitefish fleet exploiting each fishery including count of multiple fishery exploitation.

Vessel fishing strategies	CHW	HMM	NEP	OTH
Single fishery vessels		6	8	11
Two fishery vessels	17	51	32	20
Three fishery vessels	23	40	33	33
Four fishery vessels	8	8	8	8
Total number of vessels exploiting each fishery	48	105	81	72

Fishery definition: (cod, haddock, whiting – CHW; hake, monkfish, megrim – HMM; nephrops – NEP; all others – OTH).

Fig. 4. Landing weights as a fraction of total tonnage landed of main species within each fishery (cod, haddock, whiting – CHW; hake, monkfish, megrim – HMM; nephrops – NEP; all others – OTH) in 2019.

~60% of the total with the remaining split between the CHW, HMM and NEP fisheries. The OTH landings are composed mainly of lower value pelagic species such as mackerel and herring and consequently the share of revenue is much lower than the landing share. Nevertheless, this OTH share of revenue is significant, especially when assessed against the share of effort. This is logical given that pelagic species require low levels of effort due to schooling effects (Paloheimo and Dickie, 1964) while prices have been increasing and so represent a profitable fishery to enter and can be an important component of fisher annual income. The CHW fishery shares are relatively equal across effort, landings and revenue. The revenue shares of NEP equate with its effort shares while the revenue share of HMM is lower than its effort shares.

Another complicating factor when analysing the whitefish fleet is how vessels can exploit more than one fishery. In

Table 2 and Figure 5 the number of vessels that exploit from one fishery to all four fisheries is shown. Different combinations of fisheries can be exploited between the four. It is most common that two fisheries are exploited by the 136 vessels active in this segment. No vessels only exploit the CHW fishery while eight vessels only exploit the NEP fishery. The HMM fishery is the most commonly exploited fishery.

The data available also enables analysis of the significance of the nine main species caught by the case study fleet segment as bycatch species in each of the four fisheries (Fig. 4).

The top row of Figure 4 shows the landing volumes of cod, haddock and whiting with each fishery. For haddock and whiting the majority of total landings weight are from the CHW fishery however cod is sourced from the three defined fisheries to significant degrees. This is problematic in terms of fisheries management as this species is a potential choke for

Table 3. Hypothetical example of landing composition of a fishing trip.

	Volume (Tonnes)	Value (€)	Price (€/kg)	Volume share (%)	Value share (%)
Hake	3	7500	2.50	30%	31%
Monkfish	2	8000	4.00	20%	33%
Megrim	1	3500	3.50	10%	15%
Others	4	5000	1.25	40%	21%
Total	10	24 000	2.40	100%	100%

the whitefish fleet¹². The second row shows landings of hake, monkfish and megrim across the defined fisheries. For all three species at least two thirds of total landings are from the HMM fishery with the remaining landings mainly caught in the NEP fishery. Finally, nephrops is nearly exclusively landed from the NEP fishery. Mackerel and crab are exclusively caught in the OTH fishery.

4 Material and methods II: cost disaggregation

Costs that change with effort applied are fuel costs (FuC), other variable costs such as provisions or landing fees (VaC), crew costs (CrC – crew costs assumed to increase with higher effort levels) and repair and maintenance costs (RmC). Costs that do not change with effort are fixed (FxC) and capital costs (CaC). Two basic methods to assign costs will be discussed; the proportional weight method and the proportional value method.

One unit of effort in the fishery results in landings and sales of a number of species of varying quantities and sizes. Under the proportional weight method it is assumed that each species within the mix caught in the fishing nets cost the same to catch, therefore the cost per unit of effort in the fishery ($CPUE_f$) should be divided by the proportional weights of landings of all the species. In Table 3 a hypothetical example of a fishing trip is shown whereby, if vessel A, fishing in fishery HMM, lands a total of 10 tonnes of whitefish today, of which 3 tonnes are hake, 2 tonnes are monkfish, 1 tonne is megrim and the remaining 4 tonnes are a mixture of other demersal species then the cost of the monkfish component would be $0.2 * CPUE_{HMM}$.

The proportional weight method is the simplest method to disaggregate the costs however it may not be the most accurate. Under the proportional value method fishers target certain species, based on their potential value, by adapting gears and travelling to specific fishing grounds. So, in the example above where costs are disaggregated based on proportional weights the fisher may be targeting megrim and monkfish due to their higher value, but in the process of capturing these they capture other species like hake, cod, haddock and other mixed demersal stocks of lower value. Therefore, the value generated from the landings in the above example in Table 3 could result

in a total trip value of €24 000. Proportionally monkfish composes 33% of the total value of the trip so under this method the cost of the monkfish component should reflect this economic driver, $0.33 * CPUE_{HMM}$.

Other aspects on board the vessel will contribute to differing costs per species such as handling and processing. Species can be gutted, headed, tailed, filleted and winged on board involving more labour. Of the two methods of disaggregating costs, by weight and by value, it seems that the extra costs involved in on-board processing of species is better represented by the value method as this processing adds value to the landed species, which is reflected in the prices received¹³, hence this method applies a cost to this value adding process.

Annual fixed and capital costs are not affected by the level of effort applied by a vessel or fleet and hence are relatively independent of the fishery exploited. These costs are a part of the process of obtaining fish so should be incorporated in the evaluation of the economic performance of fishing segments. Just as higher on-board handling costs are likely to be justified by potential higher first sales prices, higher fixed and capital costs may be justified by the relatively higher revenues associated with participation in these fisheries.

The methodology to disaggregate costs to a species is now detailed using fuel costs as an example. To begin total annual costs are disaggregated by share of effort within each fishery. The formula for fuel cost by fishery is as follows:

$$FuC_f = FuC * \text{Effort Share}_f \quad (1)$$

where FuC_f is the total fuel costs per fishery f , FuC is the total annual fuel costs and Effort Share_f is the share of effort within fishery f , (which is calculated by division of the effort (in this case in days at sea) in fishery f by total effort in all fisheries).

Within the fishery this cost is further disaggregated by the economic value share of the selected species to the total value of the fishery. The fuel costs by species within a fishery is as follows:

$$FuC_{fs} = FuC_f * \frac{\text{Value}_{fs}}{\text{Value}_f} \quad (2)$$

where FuC_{fs} is the total fuel costs of species s within fishery f , FuC_f is the total fuel costs per fishery f , Value_f is the total value in fishery f and Value_{fs} is the total value of species s in fishery f .

Total fuel costs of species s within fishery f is now divided by the weight of landings of the species in question. The fuel

¹² Gear trials carried out by BIM aim to reduce the catches of whitefish in the nephrops fishery to prolong the exploitation within this fishery (Browne et al., 2018; Browne et al., 2018b, 2018a; Cosgrove et al., 2019; Guyader et al., 2013; McHugh et al., 2017, 2019; Tyndall et al., 2017).

¹³ See Table A.4 in Appendix for variation in prices across fisheries.

Value Shares CHW Fishery

Value Shares HMM Fishery

Value Shares NEP Fishery

Value Shares OTH Fishery

Fig. 5. Total landed value, in Euros, shares (%) of main species landed by the whitefish fleet within each fishery (cod, haddock, whiting – CHW; hake, monkfish, megrim – HMM; nephrops – NEP; all others – OTH) in 2019¹⁴.

cost per unit of species within a fishery is as follows:

$$\text{FuCPU}_{fs} = \frac{\text{FuC}_{fs}}{\text{Landing Weight}_{fs}} \quad (3)$$

where FuCPU_{fs} is the total fuel cost per unit of species s in fishery f , FuC_{fs} is the total fuel costs of species s within fishery f and $\text{Landing Weight}_{fs}$ is the weight of landings of species s within fishery f .

Finally, the total cost per unit of a species within a fishery can be calculated by following equations (1), (2), and (3) for all cost variables FuC , VaC , CrC , RmC , FxC , CaC . The total cost per unit of species s within fishery f is then:

$$\text{CPU}_{fs} = \text{FuCPU}_{fs} + \text{VaCPU}_{fs} + \text{CrCPU}_{fs} + \text{RmCPU}_{fs} + \text{FxCPU}_{fs} + \text{CaCPU}_{fs} \quad (4)$$

where CPU_{fs} is the total cost per unit of species s in fishery f , FuCPU_{fs} is the total fuel cost per unit of species s in fishery f , VaCPU_{fs} is the total variable cost per unit of species s in fishery f , CrCPU_{fs} is the total crew cost per unit of species s in fishery f , RmCPU_{fs} is the total repair and maintenance cost per unit of species s in fishery f , FxCPU_{fs} is the total fixed cost per unit of species s in fishery f and CaCPU_{fs} is the total capital cost per unit of species s in fishery f .

This methodology has been applied to the Irish polyvalent general fleet 18 m+ and the results are described in the following section.

5 Results

The Irish whitefish fleet works in mixed fisheries with diverse numbers of species caught and landed. The fisheries defined here are estimated using value shares and so do not preclude mixtures of other fishery stocks within the determined main fishing trip fishery, for instance cod or haddock in the HMM or NEP fisheries. To test the accuracy of the method in appropriately capturing these fisheries we will look at the species composition within each fishery in Figure 5.

The value of cod, haddock and whiting landed in trips assigned to the CHW fishery amount to 64% of the total value in this fishery. In landing weight terms this rises to 75%. The value of hake, monkfish and megrim within the HMM fishery amounts to 71% of the total value (62% in landing weight). In the nephrops fishery 86% of the value is from nephrops (69% in weight). Finally, in the OTH fishery the mackerel, crab and albacore fisheries compose 58% of the total value (32% in weight). In general, these results are satisfactory, as at least two thirds of the three main fisheries (CHW, HMM, NEP) are composed of the target species, and hence signal that the methodology used here assigns fishing trips to an adequate degree. As can be seen in the Figure 5c monkfish and megrim are second and third most valuable stocks in the NEP fishery.

¹⁴ See Tables 3, A.1 and A.2 in Appendix for tables of volume, value and price for main species across fisheries.

Fig. 6. Price and cost structure (fuel costs (FuC), other variable costs (VaC), crew costs (CrC), repair and maintenance costs (RmC), fixed costs (FxC), capital costs (CaC)) of main fisheries (cod, haddock, whiting – CHW; hake, monkfish, megrim – HMM; nephrops – NEP; all others – OTH) and main species exploited by the whitefish fleet in 2019¹⁵.

Despite only composing 8% of the value and 16% of the landed weight from the NEP fishery this reflects the mixed nature of demersal fisheries.

In Figure 6 the costs are aggregated per unit of the main species within each fishery along with the average prices received. Each cost variable is shown in the bars to allow comparison of the first sales price per unit of landing against operational costs and total costs including fixed and capital costs. In three of the four fisheries the unit price received is higher than the sum of all costs. The only fishery where price does not surpass all costs is the HMM fishery. In this fishery the price fails to cover all of the operational costs.

Over half of the total costs for the whitefish fleet are composed of fuel costs and crew costs. In the CHW and the NEP fisheries the average prices are above the sum of the operational costs (*FuC*, *CrC*, *VaC* and *RmC*) and the non-operational costs (*FxC* and *CaC*). In the HMM fishery prices do not cover operational costs at the unit level of the species and so this fishery generates the lowest returns to the fleet. The OTH fishery has the highest unit profitability with prices more than doubling total costs at the unit level.

In Figure 7 the average costs per unit of landings within each fishery and for all fisheries is shown for the whitefish fleet. In all fisheries but the HMM fishery the average costs are lower than the average price received per unit of fish. This results in profitable fishing activity by this fleet segment. As observed in the latest Annual Economic

Fig. 7. Price and cost structure (fuel costs (FuC), other variable costs (VaC), crew costs (CrC), repair and maintenance costs (RmC), fixed costs (FxC), capital costs (CaC)) of each fishery (cod, haddock, whiting – CHW; hake, monkfish, megrim – HMM; nephrops – NEP; all others – OTH) and for all fisheries exploited by the whitefish fleet in 2019.

Reports of European Fishing Fleets this fleet showed signs of overcapitalisation and unprofitable activity in the years before 2016 but has since generated annual net profits (STECF-20-06, 2020).

The main finding of this study is that, according to the methodology used here to disaggregate costs by fishery, the fishing activity in 2019 was also profitable in three of the main fisheries exploited by the whitefish fleet. The HMM fishery is the least profitable with average price received per

¹⁵ See Tables A.5, A.6, A.7 and A.8 in Appendix for corresponding values for each fishery.

unit covering the fuel, crew and variable costs but not completely covering repair and maintenance costs leading to a net loss per unit of fish landed. In the CHW and NEP fisheries all operational and non-operational costs are covered per unit landed. The unit profit margin in the OTH fishery can be seen to be the highest of all fisheries exploited by this fleet.

6 Discussion and conclusion

In this study a methodology has been described that allows estimation of the unit cost of fish species within mixed fisheries. The methodology has been applied to the Irish whitefish fleet (the polyvalent general fleet segments above 18 m in vessel length) and its activity in 2019 and the results show that the main fisheries exploited are profitable with one fishery generating unit losses. The price received surpasses the sum of all operational and non-operational costs signalling the capacity for this fleet segment to sustain activity in the long-term and an ability to reinvest profits into the renewal of the fleet. In this case, the margin is positive, in gross and net profit terms, for many important fishing stocks for the Irish whitefish fleet.

In three of the four fisheries categorised in this exercise the fleet demonstrates profitability with the average price received covering all costs. Only in the HMM fishery does the unit price not cover the fixed and capital costs. Despite unit losses in the HMM fishery overall the activity of the whitefish fleet is profitable and signals capacity to ensure long-term sustainability, generating resource rent that will allow the fleet to renew itself. The results here show that the OTH fishery is highly profitable given the low effort and significant value associated with it.

The methodology described in this paper allows estimation of the costs per unit of species across fisheries so the same species can present multiple catching cost structures depending on the fishery in which it is being harvested. In this exercise cod was shown to be largely caught across three fisheries. The average cost of capturing cod in each fishery ranged from €3.03/kg in the NEP fishery to €4.38/kg in the HMM fishery (€3.72/kg in CHW fishery and €1.69/kg in the OTH fishery). This shows the basic difference between how much it costs to catch cod as a target and its cost as a bycatch in another targeted fishery. This can be used in fishing policy to determine the most efficient mean of managing multiple stocks in a mixed fishery context. In certain fisheries eliminating bycatch is very difficult therefore this analysis could determine whether certain quota stocks are more efficiently exploited as a bycatch in other fisheries rather than a targeted fishery of its own. In the contrary case, knowing these costs would allow accurate cost-benefit analysis of implementing gear selectivity measures to reduce bycatch to favour targeted fisheries. This methodology could also be utilised to parametrise bio-economic models used to assess the potential impacts of alternative management plans for these fisheries and that are used to assess total allowable catch changes and quota allocations (Curtin and Keatinge, 2018).

However, these calculations are heavily influenced by landings in contrast to catches. Quota constraints and the

consequent discarding will have a very strong impact on these unitary costs as this segment may catch quantities of valuable fish in excess of the quantities they land but are forced to discard the difference due to lack of quota. If quota constraints did not exist it could thus be expected that costs per unit of species landed would fall. Additionally, following this methodology, if the fleet segment overall is unprofitable then average cost per unit must be above average price per unit. Therefore, the catch composition, particularly the main target species within each fishery, will influence the cost structure of the bycatch species in the same fishery. Other factors that may influence the unit costs include the definition of each fishery and the adequate scaling of the analysed fleet. In this application this latter aspect may play an important role as the Irish whitefish fleet has two main components; the freezer trawlers and the other vessels. The freezer trawlers are a group of vessels (~50) with freezing facilities on board the vessel that specialise on the nephrops fishery so their cost structure may vary from the whitefish fleet cost structure used in this analysis.

This analysis shows the results of the Irish whitefish fleet in 2019 and so is a static assessment of that year. It could be of benefit to include multiple years in the assessment to reflect the changing nature of fishing activity throughout time. Applying the method across multiple years would allow incorporation of the variations in price and costs and could potentially reveal insights into the dynamics at play in the exploitation of fisheries. The author is unaware of similar work that has been carried out in this line of research in the academic literature. Sandberg (2006) empirically examines how variable unit costs in Norwegian demersal and pelagic fisheries depend on output and the fish stock. Davie et al. (2014) define value per unit of effort in Irish mixed metier fisheries.

In terms of market analysis, this methodology allows the calculation of the margin that goes to the fishing sector at the first point of sale on the value chain on a species-by-species basis. This methodology could contribute to policy decision-making for fisheries managers in relation to issues relating to quota allocation and fleet management measures. Currently, several EU fleets are facing reduced quotas as a result of the UK's decision to leave the Union. Maximising the benefit of scarce quota and decisions of where (in terms of fisheries) this quota is exploited may become even more important. The socio-ecological implications of long-term planning of national fleets are considerable given the concentration of fleet segments in specific locations and the local supply chains that have developed over time. Optimising fleet structures can have direct, indirect, and induced effects at the local and regional levels and consequent effects on the ecological state of the fishery. Considering these variances in cost structures between fisheries may contribute to management plans and the development of incentives that will shape the future of national fleets.

Acknowledgments. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The author accepts responsibility for all errors that may be contained in this paper. The author would like to thank the anonymous reviewers and the editor-in-chief for their very helpful comments and advice to improve this work.

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Cite this article as: Curtin R. 2021. Disaggregating species unit costs in mixed fisheries: the case of the Irish whitefish fleet. *Aquat. Living Resour.* 34: 14

Appendix A

Table A.1. Landing statistics for hake and nephrops for the polyvalent general fleet segment +18 m in 2019.

Segment	Vessel length	Hake		Nephrops	
		Landings (Tonnes)	Value (€)	Landings (Tonnes)	Value (€)
Polyvalent general	VL1824	1771	5 440 447	3266	31 163 467
Polyvalent general	VL2440	1102	4 023 149	2299	23 281 580
Polyvalent general	VL1518	217	685 970	289	1 873 465
Polyvalent general	VL1215	156	439 206	104	926 998
Polyvalent general	VL1012	171	452 781	57	451 725
Others	All	18	92 032	13	97 532
Total		3435	11 133 584	6027	57 794 767

Table A.2. Total landings (tonnes) by the polyvalent general fleet segment +18 m of the main species within each fishery (cod, haddock, whiting – CHW; hake monkfish megrim – HMM; nephrops – NEP; all others – OTH) in 2019.

Landings (Tonnes)	CHW	HMM	NEP	OTH	Total
Cod	123	191	157	24	496
Haddock	2170	1003	283	109	3565
Whiting	1743	555	52	91	2441
Hake	296	2345	209	24	2873
Monkfish	187	2116	857	52	3212
Megrim	320	1629	395	30	2374
Norway lobster	32	114	5395	24	5565

Table A.3. Total landing value (Euros) by the polyvalent general fleet segment +18 m of the main species within each fishery (cod, haddock, whiting – CHW; hake monkfish megrim – HMM; nephrops – NEP; all others – OTH) in 2019.

Landing value (€)	CHW	HMM	NEP	OTH	Total
Cod	473 858	694 852	575 971	85 944	1 830 625
Haddock	4 733 442	2 182 242	625 505	120 863	7 662 052
Whiting	2 723 854	942 128	99 169	55 313	3 820 464
Hake	804 160	8 008 965	579 790	70 682	9 463 596
Monkfish	828 861	9 202 986	3 672 533	196 143	13 900 523
Megrim	1 039 112	5 466 220	1 218 112	61 682	7 785 126
Norway lobster	189 325	795 294	53 396 349	64 081	54 445 047

Table A.4. Average price (€/kg) by the polyvalent general fleet segment +18 m of the main species within each fishery (cod, haddock, whiting – CHW; hake monkfish megrim – HMM; nephrops – NEP; all others – OTH) in 2019.

Species	CHW	HMM	NEP	OTH	Total
Cod	3.84	3.63	3.67	3.62	3.69
Haddock	2.18	2.17	2.21	1.11	2.15
Whiting	1.56	1.70	1.93	0.61	1.57
Hake	2.72	3.42	2.78	2.98	3.29
Monkfish	4.44	4.35	4.28	3.75	4.33
Megrim	3.24	3.35	3.08	2.08	3.28
Norway lobster	5.90	6.99	9.90	2.65	9.78

Table A.5. Price and cost structure (fuel costs (FuC), other variable costs (VaC), crew costs (CrC), repair and maintenance costs (RmC), fixed costs (FxC), capital costs (CaC)) of main species exploited in the CHW fishery (cod, haddock, whiting) by the polyvalent general +18 m fleet segment in 2019.

Species	Price	FuC	VaC	RmC	FxC	CaC	CrC
Cod	3.84	0.75	0.75	0.61	0.18	0.29	1.14
Haddock	2.18	0.43	0.42	0.35	0.10	0.17	0.65
Whiting	1.56	0.31	0.30	0.25	0.07	0.12	0.47
Others	3.25	0.64	0.63	0.52	0.15	0.25	0.97
Average	2.29	0.45	0.45	0.36	0.11	0.17	0.68

Table A.6. Price and cost structure (fuel costs (FuC), other variable costs (VaC), crew costs (CrC), repair and maintenance costs (RmC), fixed costs (FxC), capital costs (CaC)) of main species exploited in the HMM fishery (hake, monkfish, megrim) by the polyvalent general +18 m fleet segment in 2019.

Species	Price	FuC	VaC	RmC	FxC	CaC	CrC
Hake	3.42	0.83	0.83	0.67	0.20	0.32	1.27
Megrim	3.35	0.82	0.81	0.66	0.20	0.32	1.24
Monkfish	4.35	1.06	1.05	0.86	0.26	0.41	1.61
Others	2.58	0.63	0.62	0.51	0.15	0.25	0.96
Average	3.29	0.80	0.80	0.65	0.19	0.31	1.22

Table A.7. Price and cost structure (fuel costs (FuC), other variable costs (VaC), crew costs (CrC), repair and maintenance costs (RmC), fixed costs (FxC), capital costs (CaC)) of main species exploited in the NEP fishery (hake, monkfish, megrim) by the polyvalent general +18 m fleet segment in 2019.

Species	Price	FuC	VaC	RmC	FxC	CaC	CrC
Norway lobster	9.90	1.66	1.64	1.34	0.40	0.64	2.51
Megrim	3.08	0.52	0.51	0.42	0.12	0.20	0.78
Monkfish	4.28	0.72	0.71	0.58	0.17	0.28	1.09
Others	3.07	0.51	0.51	0.42	0.12	0.20	0.78
Average	7.89	1.32	1.31	1.07	0.32	0.51	2.00

Table A.8. Price and cost structure (fuel costs (FuC), other variable costs (VaC), crew costs (CrC), repair and maintenance costs (RmC), fixed costs (FxC), capital costs (CaC)) of main species exploited in the OTH fishery (others) by the polyvalent general +18m fleet segment in 2019.

Species	Price	FuC	VaC	RmC	FxC	CaC	CrC
Mackerel	1.35	0.13	0.13	0.10	0.03	0.05	0.19
Crab edible	3.40	0.32	0.32	0.26	0.08	0.12	0.49
Albacore	2.26	0.21	0.21	0.17	0.05	0.08	0.32
Others	0.67	0.06	0.06	0.05	0.02	0.02	0.10
Average	1.08	0.10	0.10	0.08	0.02	0.04	0.16

Table A.9. Cost structure for 4 selected species of interest landed by the polyvalent general fleet segment +18 m in 2019.

Fishery	Species	Price _{fs}	FuCPU _{fs}	VaCPU _{fs}	RmCPU _{fs}	FxCPU _{fs}	CaCPU _{fs}	CrCPU _{fs}	CPU _{fs}
CHW	Haddock	2.18	0.43	0.42	0.35	0.10	0.17	0.65	2.12
HMM	Hake	3.42	0.83	0.83	0.67	0.20	0.32	1.27	4.12
NEP	Norway lobster	9.90	1.66	1.64	1.34	0.40	0.64	2.51	8.19
OTH	Mackerel	1.35	0.13	0.13	0.10	0.03	0.05	0.19	0.63