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Quantification of Plastics in Agriculture and Fisheries at a Regional Scale: A Case Study of South West England

Maria Eugenia Correa-Cano [1], Kerry Burton [2], Markus Mueller [1], Victor Kouloumpis [1] and Xiaoyu Yan [1,*]

1 Environment and Sustainability Institute, University of Exeter, Penryn Campus, Cornwall TR10 9FE, UK; m.e.correa-cano2@exeter.ac.uk (M.E.C.-C.); m.mueller@exeter.ac.uk (M.M.); v.kouloumpis@exeter.ac.uk (V.K.)

2 Geography Department, University of Exeter, Amory Building, Rennes Drive, Exeter EX4 4RJ, UK; k.e.burton@exeter.ac.uk

* Correspondence: xiaoyu.yan@exeter.ac.uk

Abstract: The use of plastics in agriculture and in fisheries has been vital to increase food production and meet the demands of an increasingly growing global population. However, there are several drawbacks to the use of plastics in these industries. Most plastics used in agriculture are disposed of after one single use and are highly susceptible to weathering. Abandoned, lost, or discarded fishing gear cause considerable damage to marine life. Quantification of plastic waste generation in these industries is scarce or non-existent in the case of fisheries. In this paper, we estimate the amount of plastic waste generated by agriculture and fisheries at a regional scale, considering the South West of the UK as a case study. We followed a mass balance approach to quantify the potential plastic waste generated by these industries. We find a generation of 49 kt of plastic waste in agriculture, 47% of which has an unknown fate. We estimate 454 t/year of fishing gear waste, with unclear end-of-life pathways. A detailed quantitative understanding of plastic waste generation per sector at a regional scale is fundamental for tracking plastic waste flows, locating hotspots of pollution, and planning actions to reduce the amount of plastic waste along the chain of end-users.

Keywords: waste generation; agricultural plastic waste; fishing gear; plastic pollution; plastic mulch; packaging plastics; plastic films

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1. Introduction

The world's population is expected to increase by 2 billion people in the next 30 years, from 7.7 billion currently to 9.7 billion in 2050 [1]. Although this alone poses a pressure on food production to satisfy the world needs, the increase in per capita income, urbanisation, and shifts in diet structures have become additional combining factors for food demand [2,3]. At the same time, food production needs to follow sustainable methods (e.g., using land more efficiently in the case of agriculture), adopting new technologies and processes, and including socio-economic innovation [4]. The food industry will also need to conserve natural resources and decrease waste generation [5,6], with the reduction of waste being a priority to decrease environmental impacts and risks [7].

The application of plastics to agriculture and fisheries has been crucial for increasing food production by extending food availability beyond seasonal production periods. Its application in agriculture proliferated rapidly after the successful use of polyethylene (PE) film for covering greenhouses, with the first one built in England in 1955 [8]. The uses of different polymers diversified rapidly as they help protect crops from weather, improve irrigation efficiency, and decrease the use of agrochemicals. Further incorporation of additives to stabilise the mechanical and optical properties of resin helped to lay the path for diversifying chemicals for a variety of applications, especially on PE films, which are widely used as plastic mulches, tunnels, and row covers, mainly to change soil temperature [8]. Other polymer applications for crop production include bale wrap and silage, irrigation systems, crates, and containers (see [9] for a comprehensive list and classification of plastics used in agriculture). However, most plastic products used in agriculture need to be disposed after one single use. In the UK, Valpak & WRAP [10] reported 40 kt of agricultural plastics waste (APW) generated in 2016. Although this amount is lower than household plastic packaging, 1.5 million tons, [11] or construction, 1.2 million tons [12], plastics used in agriculture have clear paths of leakage to the environment, as they are susceptible to weathering (e.g., bale wraps that are stored outdoors), there is a significant wear and tear while in use (e.g., films used for covers including plastic mulches and tunnels), and there is accumulation of resins or other toxic elements in soils after onsite processing by burying and burning [13].

Similarly, the evidence on the use of synthetic polymers in fisheries dates back to 1965 [14]. Abandoned, lost, or otherwise discarded fishing gear (ALDFG) has caused considerable damage to marine life, by entangling and killing marine fauna and sea birds and by disturbing spawning grounds and smother habitats, and ultimately, becoming fragmented [15]. Multiple sources of evidence show that the accumulation of ALDFG in the ocean is staggering. Lebreton et al. [16] reported that ALDFG represented 46% of 79,000 tons of plastic observed in the North Pacific Ocean in 2018, making fishing nets a considerable component of marine litter.

Nevertheless, quantification of plastic waste generation is scarce. In agriculture, Briassoulis et al. [13] estimated 700,000 tonnes of APW generation in Europe, analysing the quantity, quality, and composition of waste and detailing the impacts on human health and the environment. In the UK, the Environment Agency [17] reported a comprehensive quantification of non-natural waste materials using data from an extensive literature review, questionnaires, and data collected on farms in the South West and East of England. A recent review conducted by Duque-Acevedo et al. [18] analysed the evolution of publications on agricultural waste from 1931 to 2018. However, from the 3148 articles identified, the word plastics or polymer did not emerge in the keywords analysis. These studies, although highly valuable, are either dated or do not consider plastics in their inputs.

Remote sensing and GIS techniques have been increasingly applied to quantify APW [9,19–21]. However, these techniques are limited to plastic films, for instance, plastic mulch or greenhouses, which cover extensive land areas; therefore, they are not broadly applicable to every agricultural site. Recent hyperspectral imaging sensors and techniques have proved to be an aide for the quantification of plastic fragments accumulated on soils (e.g., [22]). Nevertheless, these techniques account for the remnant polymer fractions left on the ground after the removal of the plastic items used, and not for plastic waste generation. In contrast to agriculture, there is no direct quantification of plastic waste generated from fishing vessels. Nevertheless, there is an extensive literature on the quantification of marine litter, mainly focused on surveys of floating debris (e.g., [23,24]) and beach surveys (e.g., [25–27]). In addition, evidence shows that a large amount of plastic debris is discharged by fishing vessels into the sea [28–31]. Although marine plastic waste has attracted considerable attention, there is a gap in the literature regarding the quantification of plastic waste generated by vessels, particularly from fishing gear, which includes a range of the items that cause significant negative effects on marine ecosystems.

The quantification of plastic waste generation per sector is a key step to reach the proposal of the UK government's Environment Act-2021 [32] for reducing the waste that ends up in landfill or incineration in half by 2042. Additionally, it is a key step to meet the compromise made on the Leader's Pledge for Nature [33], which commits to the elimination of plastic leakage into the ocean by 2050, alongside pollution of the air, land, soil, freshwater, and the ocean. It is vital to increase the understanding of the quantity and distribution of plastic waste generated at regional scales and focusing on the food industry is a crucial step to guarantee the availability of food in a region and the sustainable use of resources. This will help to locate plastic waste hotspots and to plan required actions to stop leakage into the environment.

In this paper, we present a novel estimate of the amount of plastic waste generated for two key food production industries: agriculture and fisheries. This study is conducted at the regional scale and considers three counties in the South West of the UK as a case study: Cornwall, Devon and Somerset. To our knowledge, an estimation of plastic waste generation at this scale has not been done before, which allows us to gain understanding and identify gaps in the cycle between consumption, disposal, and waste management to lead towards a circular economy model.

2. Method

The analysis is divided in three sections: (1) case study area analysis, (2) identification and collection of regional data on plastic waste from agriculture and fisheries at the regional scale in the UK, and (3) estimation of current flows of plastic waste. The outline of the method is represented in Figure 1.

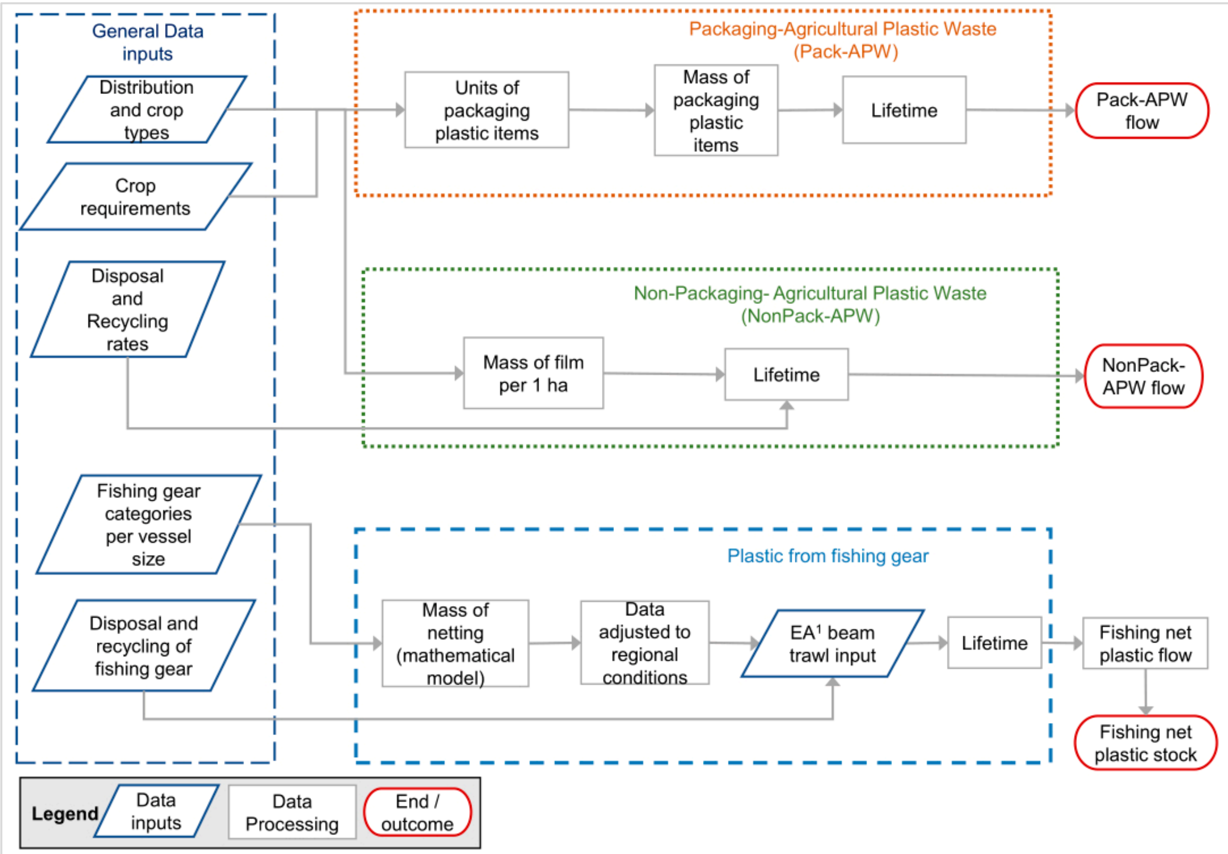

Figure 1. Method outline. [1] EA, Environment Agency.

2.1. Study Area

The South West covers 23,800 km^2 of the UK, being the largest of the nine regions of England (Figure 2). The region is largely rural, with a population of 5.7 million people [34]. It has the longest coastline of all English regions with a total length of 1014 km. The region had a gross value added, generated from agriculture, forestry, and fishing, of 16%, or GBP 1.4 billion, in 2017 [35]. Grazing livestock farms accounted for 35% of the farmed area in 2019, with cereal and dairy farms accounting for 20% and 18%, respectively [36]. Milk production, plants and flowers, cattle for meat, and poultry meat together accounted for 57% of the total value of the output [36]. Regarding fisheries, three of the 18 ports in the region (Brixham, Newlyn, and Plymouth) contribute to a third of all landings in England, or 27.62 kt [37]. The total household waste produced in the South West was 2690 tons during 2021–2022, from which 49% is recycled, 44% is sent to incineration, and 6% is sent to landfill [38]. In this study, we have focused on three of the seven sub-regions: Cornwall (excluding the Isles of Scilly), Devon and Somerset.

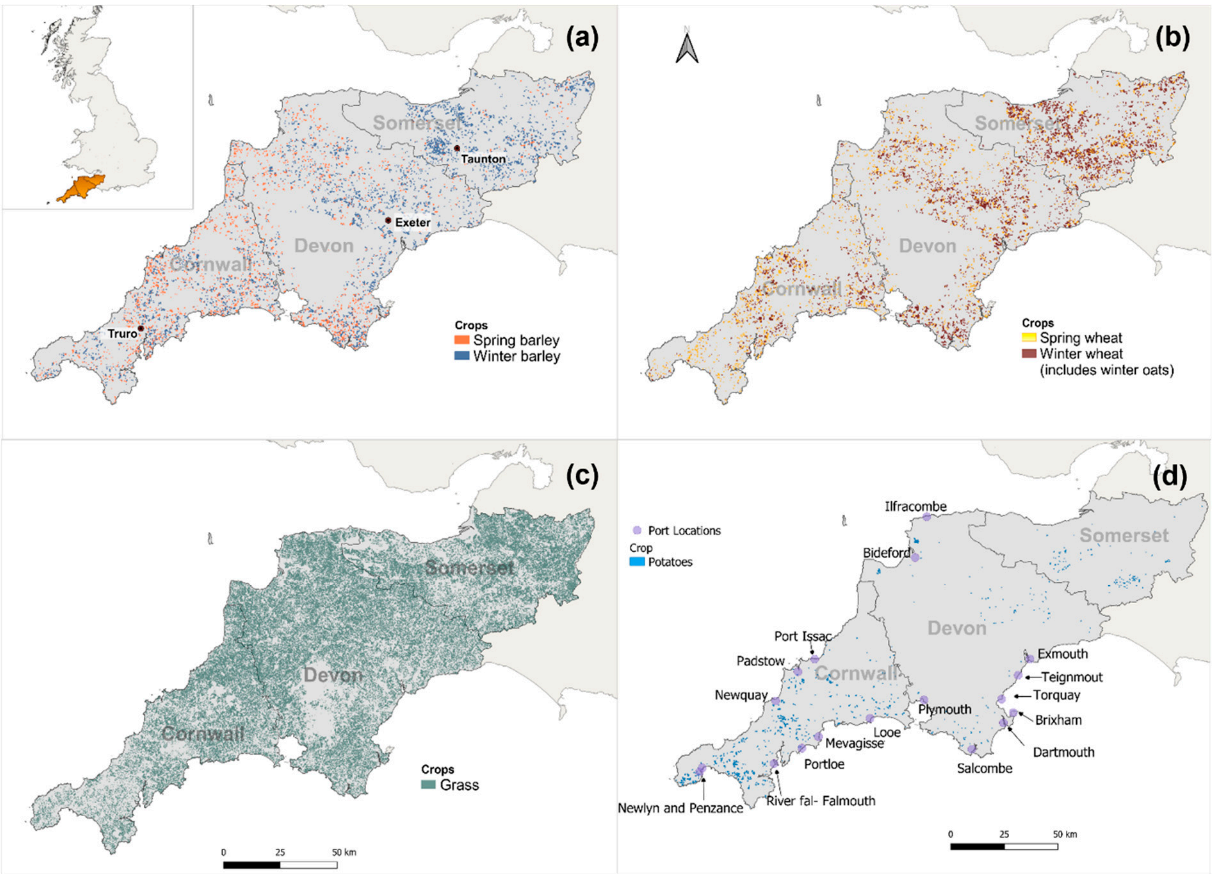

Figure 2. Distribution of selected crops and location of ports in the case study area. (**a**) Distribution of spring and winter barley, (**b**) distribution of spring wheat and winter wheat and oats, (**c**) distribution of grass, and (**d**) distribution of potatoes and ports, as reported by [37].

2.2. Data Sources of Plastic Waste

We conducted an exhaustive search in the scientific and grey literature to locate published sources of plastic waste generated from agriculture and fisheries at the regional scale in the UK. For agriculture, we conducted a search for published peer-reviewed articles in three scientific bibliographic databases: Science Direct, Scopus, and Google Scholar, using a string with words referring to agriculture, plastic, and waste (agricultur* AND plastic* AND waste OR dispos* OR management OR recycling OR plasticulture OR landfill OR refuse OR dumpsite OR collection). We found a total of 4132 publications which were refined by title to select suitable articles. We considered a total of 578 publications and selected those relating to the UK. Only 6 publications were associated with the country, and none directly related to monitoring or accounting for agricultural plastic waste. In addition, we found 12 reports and brief papers from governmental and other organisations related to agriculture for the South West and agriculture and plastics at the national scale. National datasets of generated waste contain highly aggregated information (e.g., Waste Data Interrogator from the Environment Agency), and given that packaging has been recognised as one of the largest pollutants, especially from plastic packaging [39], the Environment Agency developed The National Packaging Waste Database, which is also highly aggregated without detailed information at regional scales.

Regarding fisheries, we conducted a search of marine and fisheries datasets for the UK using Google search engine. The existing databases are focused on recording historical catch and effort charts as well as marine litter data (some examples from [40,41]).

Given the lack of data availability on plastic waste generated by agriculture or fisheries at a regional scale, we conducted our estimations using a mass balance approach. In this method, the mass entering and leaving the system is quantified, allowing for unknown mass flows to be measured. In addition, from a static material flow analysis perspective, flows are defined as the ratio of mass per time [42]; therefore, we assumed that: (1) plastic items needed for growing crops and the amount of fishing gear needed per vessel in fisheries will become waste (Figure 1), and (2) we defined plastic flow as the ratio of the plastic waste weight generated in a year, originated either by agriculture or by using fishing gear. We did not consider stock for agricultural waste as most of the plastic for this industry is single use. We used national and European estimates of plastic disposal to assess the amount diverted to end-of-life pathways for agricultural plastic. Regarding fisheries, we conducted a survey directed to Harbour Masters and fleet managers in the South West.

2.3. Agriculture

2.3.1. Crop Selection in the South West

We selected four crops as a proxy for the 11 crops produced in the region. The chosen crops are important for livestock as the region accounts for a third of the total national dairy and beef herds [36]. We selected wheat and barley, which are consumed essentially as animal feed; grass which is used primarily for silage production; and potatoes as a representative of a crop that needs plastic mulch during the early stages of production. We considered the differences of production needs between spring and winter for barley and wheat. Despite the proportion of farms growing maize and oilseed rape (Table S1 Supplementary Information), we did not select those crops given the contrasting and scarce information available regarding growth requirements. The chosen crops cover more than 90% of the total agricultural land surface.

Data regarding the type of crop and their extent in the South West per county (Cornwall, Devon and Somerset) were obtained from the CEH Land Cover® Plus [43] acquired from Edina. Vector layers for each individual crop were selected and exported for further processing into Excel and using QGIS v. 3.4 [44] (Figure 2). The total agricultural land per crop in the SW can be found in Table S1, Supplementary Information.

2.3.2. Packaging Agricultural Plastic Waste (Pack-APW)

Plastic packaging included in this study comprises containers for agrochemicals (i.e., fertilisers, herbicides, fungicides, and growth regulator) and seed bags. We considered packaging waste as the plastic items generated after the use of those items. These categories are based on the Environment Agency [17] classification of non-natural agricultural waste. All estimations were made per crop and per county. The total number of plastic packaging items used per crop was calculated per unit area (ha) based on the requirements of each crop. Crop requirements were determined for the varieties of wheat and barley recommended for the South West by the Agriculture and Horticulture Development Board (AHDB, [45]) for 2018–2019. Based on the suggested varieties, we extracted information regarding seed rates and followed the recommended agrochemical application from the AHDB per unit area when available. Additional agrochemical amounts were extracted directly from the packaging of common commercial products offered in the UK. We then calculated the number of seed sacks and fertiliser containers per hectare for each type of grain and per season. To estimate the weight of the plastic packaging used, we used Google search engine to extract information on the capacity, size, weight, and polymer type of the individual plastic packaging items (i.e., seed sacks and agrochemical containers) as reported by available providers for the UK. Further, we multiplied the weight of one packaging item for each category by the total number of items required per hectare to obtain the total weight per unit area.

2.3.3. Non-Packaging Agricultural Plastic Waste (NonPack-APW)

Low Density Polyethylene (LDPE) is used in the production of between 70 and 85% of all agricultural products [46]; therefore, we assumed that all plastic film used for wrap baling and plastic mulching used during potato production is LDPE. For both films, we considered the dimensions of a commercial film-roll product (i.e., wide, length, and thickness) to estimate the mass of film per unit area (ha). For bale wraps, we adjusted the number of layers needed per bale following farmers' recommendations from the online farming forum [47]. Therefore, we considered that each bale used 6 layers of film from one of the most common rolls used ($0.75 \times 1500 \times 2.5 \times 10^{-5}$ m, width, length, thickness, respectively). Second, we obtained the total volume of film used per unit area, by multiplying the total plastic used per bale by the potential total number of bales produced in one hectare (24.71 bales, [47]). We then obtained the total plastic weight by multiplying the volume per hectare by the weight of one m^3 of LDPE (910 kg).

Similar to the estimation of bale wrap, we used the film mulch dimensions from a commercial product to calculate the volume of the plastic mulch used in one hectare, considering 1.83 m space between rows which is not covered by mulch. We then considered the minimum LDPE density (910 g/cm^3) to estimate the weight of two types of films commonly found in commercial plastic mulch (with thickness of 20 μm and 100 μm) to obtain a range of values. Although farmers can adjust mulch type with soil variety and weather conditions, we assumed a similar range of weather across the South West. It was not possible to adjust for soil types or microclimatic conditions. Biodegradable, bio-based, and compostable mulches are out of the scope of this study.

2.3.4. End-of-Life Pathways

Quantification of the end-of-life pathways was conducted following diverse sources of information and estimated independently for Pack-APW and NonPack-APW. From Plastics Europe [48], we considered the proportion of Pack-APW directed to landfill, recycling, or to a waste-to-energy facility, where incineration is used to recover Energy from Waste (EfW). The proportion sent to the export market was based on estimations from WRAP [10]. The proportion of NonPack-APW sent to landfill, recycling, waste-to-energy and export market was estimated based on [10]. For both packaging and non-packaging plastic waste, The Farm Practices Survey [49] was used to calculate the proportion of waste going to residual waste, collected by a specialist waste collector, re-use on farm, and other.

2.4. Fishing Nets

2.4.1. Port Location, Vessel Sizes and Fishing Gear Categories

The total amount of fishing net waste generated for the South Waste was estimated based on two assumptions. First, that the mathematical model of a drift and/or fixed net is equivalent for all these types of fishing gear, and second, that all beam trawlers use the same amount of gear (the total weight of its components is the same for all vessels). We used the number of vessels reported in the 'Summary of fleet landings for 2017' [50] for each of the 18 ports located in the South West (Figure 2c) to extract the number of vessels, their dimensions, and the gear category used per vessel size. We selected two of the seven fishing gear categories reported: drift and fixed gear, and beam trawl. Drift and fixed gear were selected due to their geometrical shape and their viability to develop a mathematical model (Figure 3). Beam trawl was selected because the Environment Agency has developed a detailed quantification of the materials used to assemble this type of fishing gear through a pilot project in Brixham, Devon [49]. We did not consider demersal/trawl seine (which is used by 35% of vessels) due to the lack of information on the specific characteristics of this gear for the South West and due to the complexity of the net components to be represented mathematically. We also excluded pelagic seine, as we did not have enough information for their use in the region; dredge, as its components are mostly metallic; and pots and traps, due to the variety of materials and designs available. Finally, we disregarded the category "other" because of its ambiguity.

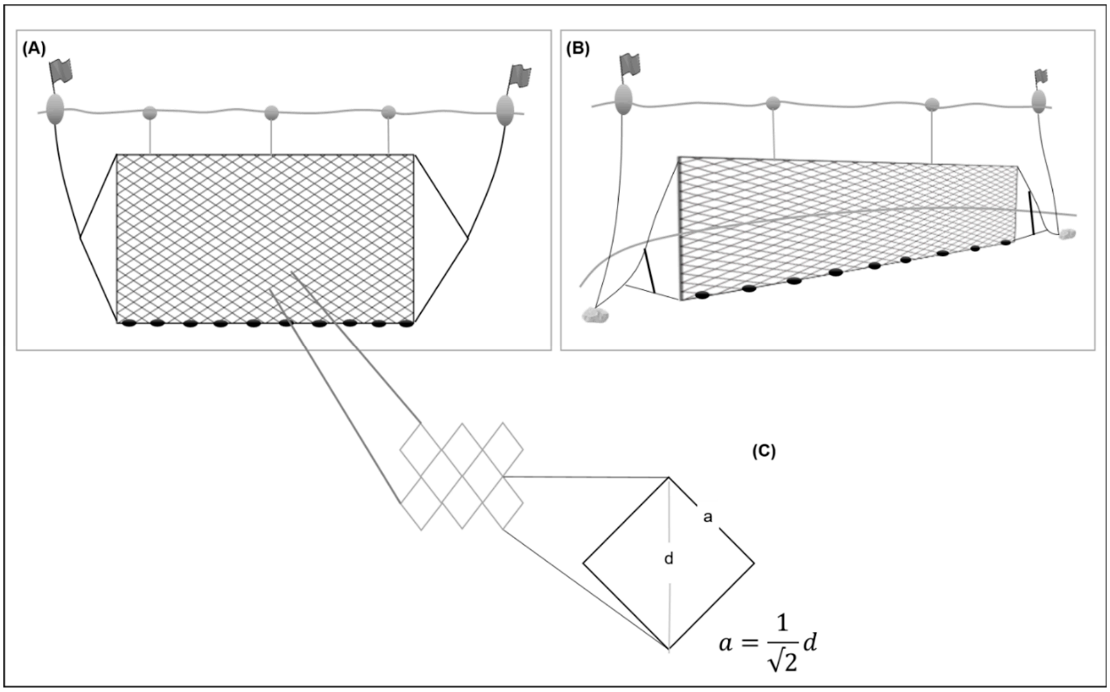

Figure 3. Idealised elements of fishing gear using gillnets. (**A**) Drift gillnet, (**B**) fixed or set gillnet, and (**C**) representation of a mesh in diamond-like shape. We considered a knotless netting with a diamond mesh, where d is the diagonal of a square (mesh size), and a is the side of a square.

2.4.2. Harbour Masters and Fleet Managers Survey

With the aim of understanding the path that fishing gear waste follows after the end of its life we conducted a survey targeted to fleet managers and Harbour Masters in the South West. Data was collected via an online survey sent to each harbour in the South West. No identifying data was collected (nor location nor names). A statement at the start of the survey informed them that the information was intended to be used for research purposes and to understand plastics in the South West only. The survey included questions related to the disposal facilities at each port, the end-of-use pathways, and challenges that need to be addressed in order to increase appropriate disposal of fishing gear. The full set of questions can be consulted in Supplementary Materials Data S1.

2.4.3. Mathematical Model for a Net

Each individual component of a fishing gear can be mathematically modelled; therefore, we developed a numerical model to estimate the weight of idealised elements of a net for drift and fixed gears (Figure 3). Further adjustments were made based on experts' revisions for typical fishing nets used in the South West. Data for beam trawl were directly obtained from [51].

We have assumed that a drift and/or fixed net has a length l and height h, and that it is formed by diamond-like mesh of x size, represented by the diagonal d (Figure 3). We estimated the value of a following $a = \frac{1}{\sqrt{2}} d$. In this model, we are assuming that the net does not have a joining knot between two meshes; therefore, no extra twine was added. The mesh size x varies depending on the targeted fish, twine thickness, and material; however, we considered the mesh size usually used in the region as reported by [52] and after communication with a fisher manager based in Newlyn Port, Cornwall.

The amount of twine per rhomboid t_r was obtained by multiplying one side by 4, that is $t_r = a * 4$. Considering that the number of meshes at length l is given by M_l and that the number of meshes at depth d is given by M_d, the total length of twine Tt in a net is given by $Tt = t_r * (M_l * M_d)$. We applied the equation for the volume of a cylinder $V = \pi * r^2 Tt$ to obtain the volume of the total twine, where r is the radius of the twine. Finally, we estimated the mass of the net, m, in kg by multiplying the volume by the density of the specific plastic material ρ following $m = V * \rho$.

2.4.4. Fisheries Plastic Flow and Stock

For the plastic flow, the weight of one net was multiplied by the frequency in which the net needs to be replaced in a period of 12 months. Drift nets and fixed gears need to be replaced on average every three months. Trawl netting can usually last 1–1.5 years (based on information from the fleet manager survey); therefore, we considered the average rate use (1.25 years) of one net, and the proportion of use of 0.8 in one year for trawl netting. We did not take into account fishing seasonality.

The plastic stock was calculated as the product of the proportion of one netting that was not discarded in one year by the total number of fishing vessels using the specific fishing gear.

2.5. Comparison with Other Published Data

To be able to compare the APW results of the current study, we adjusted national averages to the area covered by the three counties under study. We also added a 70% of NonPack-APW that is not collected as reported by [53]. Following [17], we added 50% w/w contamination for silage and mulch to our estimates as national estimations already account for this. National averages included The Chartered Institution of Wastes Management (CIWM) [54], the estimation published by Valpak & WRAP [10], the assessment conducted by the Environment Agency [17], and data on agricultural plastic waste obtained from the Farming & Wildlife Advisory Group (FWAG) for the South West from 2004 to 2019 [55].

It was not possible to compare waste generated by discarded fishing gear as it was not a published metric at the national or regional scale at the time of the current study.

3. Results

3.1. Agricultural Plastic Waste

The total estimated APW generated for the SW is 49,106 t/year. From this, 982 t (2%) are Pack-APW and 98% (48,124 t) correspond to NonPack-APW. The average Pack-APW annual flow per unit area in the South West equals 1.28 ± 0.14 kg/ha.

Devon generates the largest amount of Pack-APW (46%), although it is also the largest county of the three. Therefore, after controlling for differences in farmed area, we determined that Somerset is the county generating proportionally the largest amount of Pack-APW, followed by Devon and Cornwall (Figure 4a). Winter and spring barley are the crops which generate the largest amount of Pack-APW, with winter wheat and oats generating a similar rate to spring barley (1290 vs. 1244). Potato generates significantly less Pack-APW than the rest of the crops (Figure 4b).

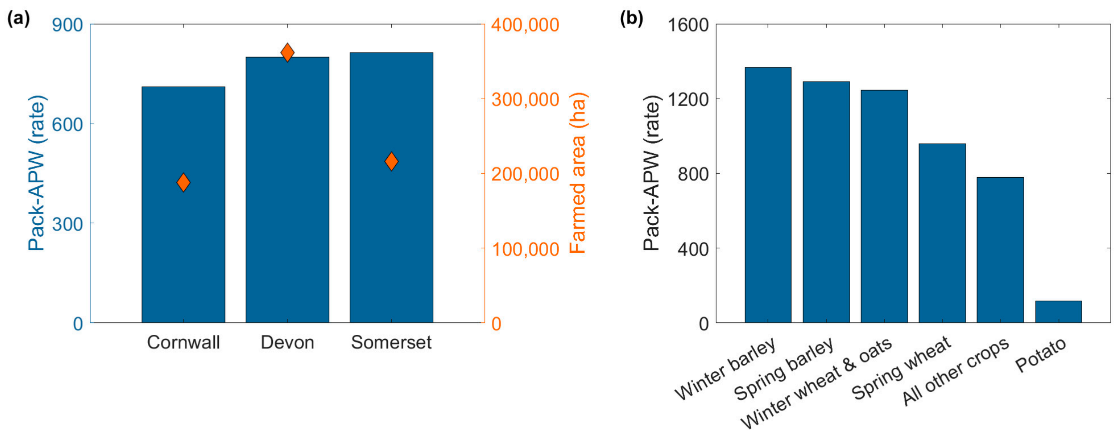

Figure 4. (**a**) Packaging-APW rate for each South West county. Rhomboids indicate the total farmed area, including grassland for pasture, (**b**) packaging waste rates generated by crop type.

From the total amount of NonPack-APW (48,124 t), 96% is generated by silage wrap and 4% by plastic mulch. The annual flow per unit area is of 31.6 kg/ha for silage wrap and 82.01 kg/ha for mulch film.

The end-of-life pathways for the total APW generated is represented in Figure 5. From the total APW generated, 38% is diverted to residual waste, 34% is collected by a private company, 3% is reused in farms, and 25% has other unknown pathways.

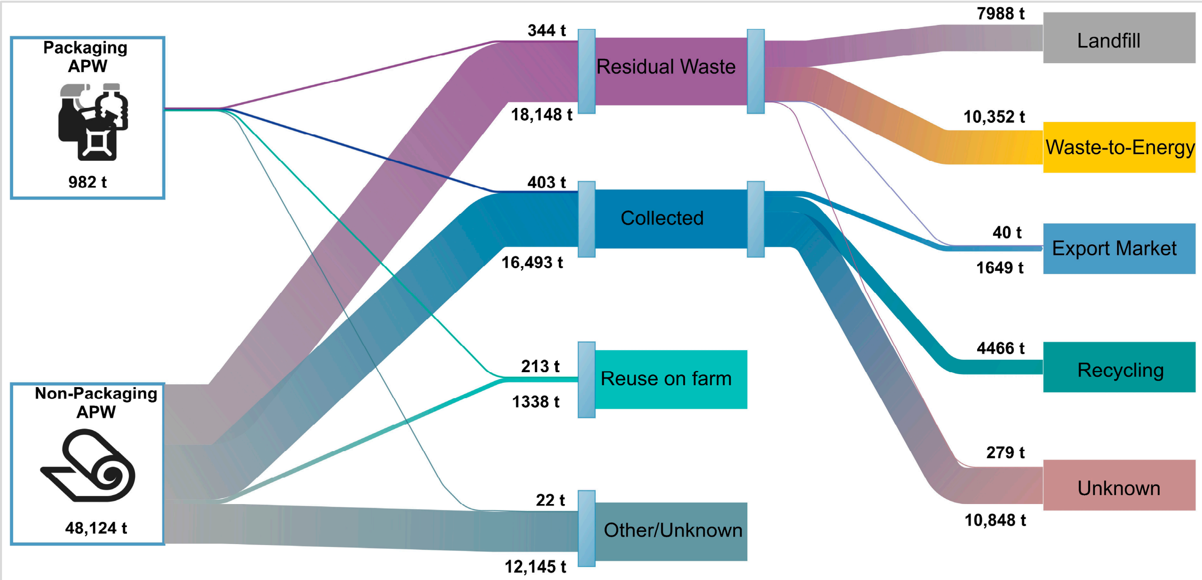

Figure 5. End-of-life pathways for APW in the South West.

Most of the residual waste is directed to landfill and incineration to obtain energy from waste (43% and 55%, respectively), with the smaller proportion sent to the export market (0.22%), and 1.5% of unknown destination.

From the collected APW, 10, 848 is of unknown fate (66%), 4466 t is sent to recycling, and 1649 t to the export market.

Adjusted amounts of APW for the South West from data at the national scale show a disparity between external sources and with the current study. For Pack-APW, FWAG reported the highest quantity for the region (9760 t), followed by the estimation from CIWM (Table 1). The amount calculated by the current study is the lowest (982 t) of the five sources. After accounting for 50% contamination in Non-Pack-APW, and after adding 70% of waste that is not collected to the external data, the result on this study is the highest (72,286 t), followed by CIWM, WRAP and the EA (Table 1).

Table 1. Comparison of agricultural plastic waste estimates with publicly available reports. All amounts are adjusted to the proportional area in the South West, UK. NI: No information.

Source of Information	Total Packaging (t) for the SW	NonP-APW (t) with Contamination Considering SW Farmed Area *	Adding the 70% That Is Not Collected to External Sources (with Contamination) **
This study	982	72,286	72,286
CIWM	2669	12,948	22,012
WRAP	NI	4775	15,916
EA	1135 ***	4678	15,593
FWAG	9760	NI	NI

* The total farmed area considered is 765,297 ha for Cornwall, Devon and Somerset. ** Considering that only 30% of NonPack-APW is collected in the UK (Plastics and Environment, 2019, https://ape-uk.com/ accessed on 4 March 2020). *** The amount corresponds to agrochemical packaging, fertiliser bags, and seed bags.

3.2. Fisheries Plastic Waste

The number of vessels over 10 m using beam trawl (2127) is considerably larger than vessels of 10 m and under using this method (12 vessels, Table 2). From a total of 18 ports in the South West, 33% received fish from vessels over 10 m using beam trawl and only one port (Brixham) received fish from vessels of 10 m and under using the same gear. In contrast, 77% and 88% of ports received fish landed by vessels of over 10 m and of 10 m and under, respectively, using fixed and drift nets (Table 2).

Table 2. Total number of vessels per fishing gear category and the number of ports of landing for each category of vessel size category in 2017.

Vessel Size Category	No. of Beam Trawl Vessels	No. of Ports of Landing Beam Trawl Vessels	No. of Drift and Fixed Nets Vessels	No. of Ports of Landing Drift and Fixed Nets	Total No. of Vessels
10 m and under	12	1	3519	16	3531
over 10 m	2127	6	980	14	3107
Total	2139		4499		6638

The total annual flow for fishing nets in the South West in 2017 was of 454.23 t, and the largest flow is from beam trawls of over 10 m, contributing 237.7 t/year of netting (Figure 6). Drift and fixed nets have no stock in a year, and the rate of net substitution accumulates 216.56 t/year. Somerset is the county that contributes the least to the plastic flow from fisheries, due to the low number of vessels that land fish in their ports.

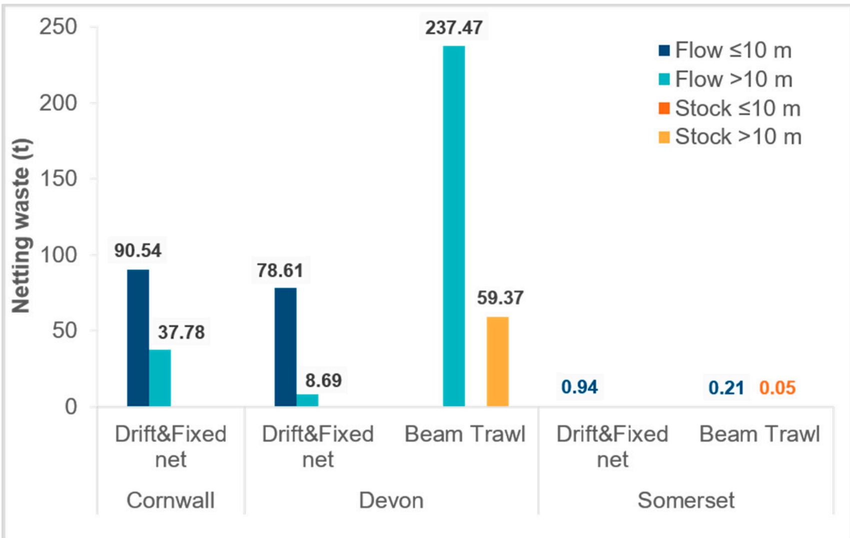

Figure 6. Flow and stock of fishing gear for the South West for 2017. Fishing net waste generated by vessels of 10 m and under (≤10), and waste generated from vessels of over 10 m (>10).

Disposal of Waste from Fisheries According to Surveys

We received eight out of 18 possible responses from Harbour Masters (44%), assuming that there is one Harbour Master per port, and one response from a fleet manager, the latter not being representative and is therefore not presented as a result. From the Harbour Master responses, 75% of the ports have facilities for receiving fishing vessel waste (Figure 7). Only 50% of the ports can send fishing netting to recycle through established collaborations with specialist fishing waste recovery projects (e.g., fishing for litter).

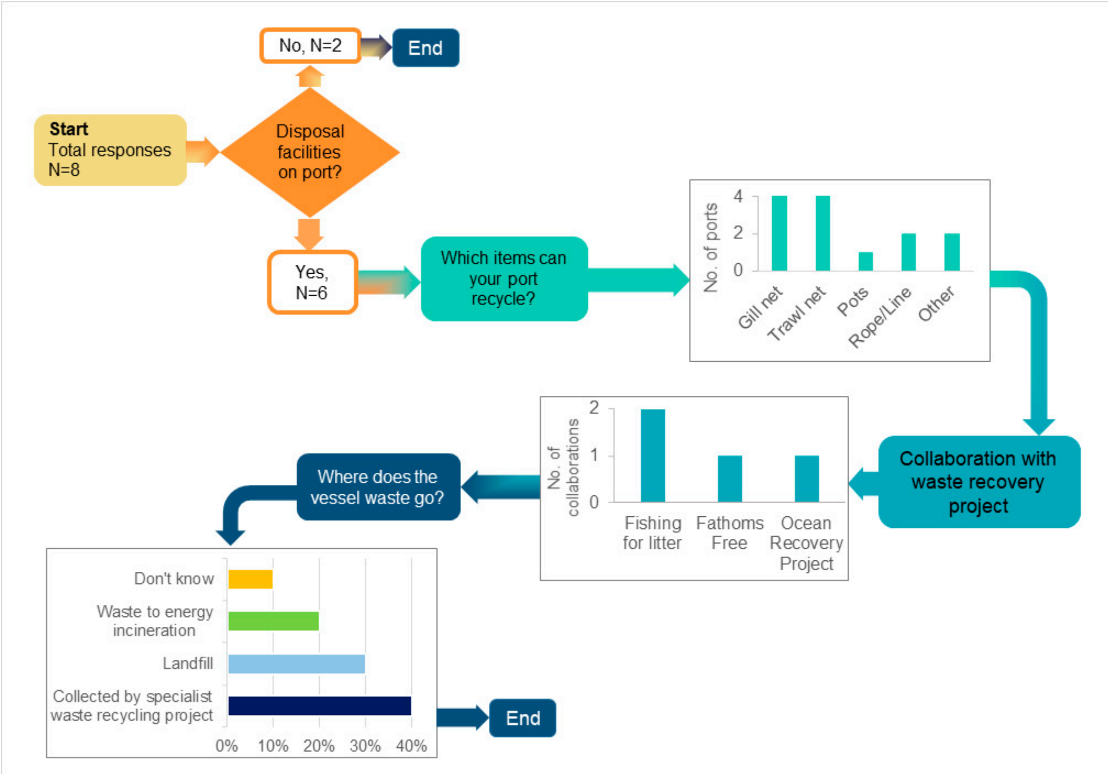

Figure 7. Flowchart for the questions and answers related to vessel waste disposal from Harbour Masters in the region. The total number of responses received was eight and the respondents could reply to more than one option.

The fate of the collected fishing gear waste was reported as mixed. One port stated that waste is sent to the landfill, two ports reported a mix of pathway methods (waste to energy incineration, landfill, and collected by a special waste recycling project), and two additional ports did not provide further information.

The main challenges reported affecting the provision of waste or recycling facilities include cost of disposal and space.

Although ports are not charging fisherman for waste disposal, in 2020, the cost of waste disposal was GBP 110 per tonne, as reported by survey responses. One port reported generating 5 tonnes of waste per week, which, assuming a constant rate of waste generation through the year, would be a total of 260 tonnes in a year with an annual cost of disposal of GBP 28,600.

4. Discussion

Plastics in agriculture and fisheries are crucial for food production and are an aide to meet the global increase in food demand. As food demand increases, food production increases and, therefore, the demand for plastics in these sectors increases. Plastic waste generation is at an alarming level and it needs to be quantified at different scales. This study is the first attempt of estimating plastic waste generation for food sectors at a regional scale. Our result for Pack-APW is comparable to the Environment Agency estimations published in 2001 for the South West (982 t and 1135 t, respectively). The estimation of NonPack-APW on this study including contamination is higher than the amount reported by all other sources. Nevertheless, quantities between published sources are disparate. Estimations made by WRAP [10] for both types of waste are considerably lower than the amount reported by CIWM and the current study, although comparable to the Environment Agency results [17]. Given the large differences between APW estimations, particularly for the generation of non-packaging waste, it is crucial to develop a fast track and accessible method to accurately estimate the total waste generated, including the end-of-life pathways. From our results, the proportional amount of waste ending up in the export market (10%) and of unknown destination (66%) is alarming. Bishop et al. [56] identified the United Kingdom as one the top three countries contributing to the ocean debris as a consequence of exporting polyethylene to be recycled. Additional evidence shows that the UK has increased the amount of plastic waste exports from 12,000 tons in 2016 to 209,642 tons in 2020 [57], and the Environment Agency [58] reported an increasing amount of contaminated plastic waste destined for illegal export in that year, mainly composed from agricultural plastic waste. In 2022 alone, the UK exported 0.48 million tons of plastic waste [59].

Current on-farm collection schemes or delivery at local collection points do not have standardised methods or costs. The normal process of collection includes requests of the delivery of cleaned waste before being bailed in special containers, which are usually provided by the collection company (at an extra cost). Although cleaning of plastic waste is understandable in terms of waste transportation and further reprocessing, cleaning on site is time and resource consuming for farmers, and they will often need to store mulches or bale wrapping before starting the cleaning process for an unknown period of time. Space is a limiting factor for small farmers (<5 ha farms) and farmers might decide to dispose of it by burying or burning it on site without paying for special collection. On the one hand, there is an urgent need for standardisation of collection, and for schemes that help farmers handle waste on site (cleaning and sorting). On the other hand, the need for information regarding the use and disposal of plastics at the regional scale is clear. The development of an online national hub for APW management with the aim of quantifying and registering APW fate will be an asset in reducing plastic waste reaching the environment. It will also provide an opportunity for developing a responsible waste management scheme that could be applied by farmers and waste management companies as economic compensation for those who report good waste practices. Additional support, like the UK National Collection Scheme launched in 2019 by [53] which aimed to increase the amount of NonPack-APW collected by reducing the cost of collection for farmers, or regional projects like the Farming & Wildlife Advisory Group, can be integrated into the hub as an extra tool for increasing recycling rates and proper APW management. The South West of the UK region contains two national parks, Dartmoor and Exmoor, and about 27% of Cornwall has special landscape protection being treated as an Area of Outstanding Natural Beauty under the National Parks and Access to the Countryside Act 1949. Therefore, it is vital to keep terrestrial ecosystems free of plastics and contaminants.

Regarding fishing gear, this tool gives a good indication of the plastic waste flow for two types of gear in a specific region. It enables the estimation of annual waste generation for any type of vessel using the same gear, making appropriate mesh size adjustments. Although currently there are no datasets or reports in the UK that allow a comparison to our results, the total plastic flow waste for the fishing gear types considered is staggering (454.23 t) given that there are no clear paths for their end of life. However, Deshpande et al. [31] found that commercial fishing alone contributes nearly 380 t/year of plastics lost to the ocean in Norway.

In this study, the implementation of a survey directed to Harbour Masters was essential to adjust our data. We identified several issues stopping harbours from disposing and recycling vessel waste generated on board, the most important being lack of space in the port for allocation of waste and the high cost of disposal. Other issues include the difficulty of separation of nets from ropes and debris and a lack of specialist recyclers who collect the waste. Recycling fishing nets requires special equipment, and at the time of this research, there was one small company in the South West (Fishing Filaments, https://fishyfilaments.com, accessed 29 January 2021) recycling gillnets to produce 3D printing filaments. There is a need to incentivise recycling companies to develop special machinery focused on managing and recycling fishing nets, as well as to become established in the region. There are few recycle companies that can reprocess fishing gear in Europe, and we only identified two recycling companies: Plastix, in Denmark and Impact Solutions in Scotland. The lack of infrastructure for reprocessing and recycling fishing gear in the UK is clear, and community organisations and other projects helping to clean the sea and beaches need assistance with sending collected litter to recycling companies. One of the three aims of 'The New Plastics Economy' (2016) was to increase circular economy research towards products that are difficult to recover due to their composition and design (making 30% of all plastics). In the South West, there is great potential to increase circularity in the fishing industry by integrating all current actors and by aiding them to connect, driving efforts towards technology innovation and monitoring.

5. Limitations

Agricultural estimations for NonPack-APW are based on one type of film and do not cover the range of regional practices that make use of the variety of LLDPE in the market. Different crops in the region might require plastic mulch or plastic covering, particularly in early spring to avoid frost damage; however, we only considered the use for potato crops.

Due to the short duration of the project, the type of fishing gear considered, although some of the most important for the region, was not comprehensive. In addition, given the different characteristics of each gear type, our model cannot be extrapolated to other gear types. We did not consider demersal trawl or seines, which are broadly used by vessels of both categories. These types of nets might be larger and heavier than beam trawl gear, and to account for the amount of waste generated by its use is imperative.

6. Conclusions

The larger proportion of plastic waste generated by agriculture is LDPE used in plastic mulches and bale wraps. However, 47% of the total waste generated has an unknown fate. This is alarming as a large amount of plastic can potentially enter the environment if it is unmanaged. The end-of-life pathways of plastic waste generated from fishing nets are unknown. Information collected from Harbour Masters showed the need for implementing clearer collection and reprocessing routes from plastic waste generated by vessels. It also revealed the need to install more facilities in harbours to deposit plastic waste from vessels and help harbours cope with the cost of collection. However, we identified only two reprocessing companies that can recycle fishing nets in the country; therefore, it is crucial that recycling plant businesses expand their facilities to accept fishing nets.

This was the first regional estimation of plastic waste generated by agriculture and fisheries in the UK. It highlights the need of continuous monitoring of plastic waste generation and end-of-life pathways at regional scales. Regular monitoring will allow prompt identification of hotspots of pollution and will be an aide to local governments and businesses to improve procedures regarding waste management. Ultimately, the greater benefit will be for the environment and human health, as it will help to lower the proportion of plastics entering soils, watercourses, and air.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/recycling8060099/s1, Table S1: Total agricultural land per crop grown in the SW in 2018 in hectares; Table S2: Assumptions used to calculate the total packaging waste generation for agricultural activities in the South West, UK; Data S1: Questions send to Fleet managers and Harbour Masters of the South West of the UK.

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