Exploration of optimisation modelling in the Scottish nephrops fleet
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October 2019

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Investing in Sustainable Fisheries
Executive Summary

The Scottish Government wishes to expand its evidence base in support of its Future of Fisheries Management programme of work. The focus of this commissioned research is the economics of the Scottish nephrops fleet, and the study is a demonstration of whether, and how, existing national datasets can be used in a novel way to enhance understanding of the industry and support decision-making.

The study asks a question ‘can optimisation modelling be used in the Scottish nephrops fishing industry, and if so, what can it tell us?’

The study team has undertaken two connected analyses in order to respond to the question:

- an industry mapping analysis to establish a more detailed spatial baseline of activity alongside economic analysis of a Scottish nephrops fleet divided into 25 fleet segments; and
- optimisation modelling to test what the maximum value, in terms of gross value added (GVA), and maximum employment, in terms of full-time equivalents (FTEs), could be from the Scottish nephrops fleet.

The project has had access to never before used data for the under 10m fleet. While data challenges do remain, the availability of new data for small-scale fishing fleets has allowed for a more detailed spatial analysis of the activity of the Scottish nephrops fleet.

Industry mapping

The industry mapping undertaken for the study used existing datasets detailing the activity and economic performance of the Scottish nephrops fleet to produce a baseline analysis of the Scottish nephrops fleet by fleet segment. Twenty-five Scottish nephrops fleet segments were defined by a combination of gear type, vessel size, main location and dependency upon nephrops.

The industry mapping process allocated the activity of the 25 fleet segments to 355 distinct spatial areas around the Scottish coast. The spatial areas are broadly defined by distance from coast (buffer zones) and ICES rectangle boundaries. A key challenge in the allocation of activity to spatial area is the translation of 2017 VMS and FISH1 location data into time spent and catch taken from each spatial area.

The findings of the industry mapping process include information on gear, species caught and effort by spatial area, and the economic performance of each fleet segment.

The allocation of activity to spatial areas allowed the identification of localised hotspots of activity where there is both relatively intense fishing and a relatively high degree of interaction between the two main gear types: trawl and creel.

The analysis of economic performance by fleet segment demonstrates the high degree of variation that exists between different fleet segments. The following summarises key findings:

- in general, GVA as a percentage of revenue is higher for creel fleet segments than for trawl fleet segments; however,
- when GVA performance is presented as a ratio of GVA to FTE, several of the trawl fleets outperform the majority of creel fleet segments.
These two different views of the performance of the nephrops fleet indicate the impact of the different business models adopted by creel and trawl vessels and how challenging comparison can be between the two business models. However, the difference noted above is not apparent across all fleet segments, some creel and trawl fleets do outperform or underperform the average for their sector in each view of performance.

The industry mapping also demonstrated how mobile both creel and trawl vessels can be, with very few of the fleet segments remaining wholly within their ‘home’ functional unit (FU). However, this does not mean that all vessels in a fleet segment move between FUs.

**Optimisation modelling**

An optimisation model was developed to analyse the Scottish nephrops fleet. The model does not include the supply chain.

The purpose of the model is to explore what might happen if all Scottish nephrops fleet activity was driven by a single objective. The two objectives specified by the Scottish Government for testing in the optimisation model are:

- **Scenario 1** – what might the maximum GVA of the Scottish nephrops fleet be; and
- **Scenario 2** – what might the maximum employment in the Scottish nephrops fleet be.

In an unconstrained optimisation, the model will find the fleet that best provides the maximum value under a specified objective and give all the opportunity to that fleet. However, this would ignore reality. For example, it would be infeasible to catch all Scottish nephrops in the way, and at the location, that one fleet fishes. For this reason, constraints are required to establish a balance between realism and providing the model with freedom to explore alternative scenarios. Inevitably, the selection of constraints guides the output.

The creation of the model required several cycles of development, testing and review in order to find appropriate constraints. Sensitivity analyses were used to understand the effect of some constraints and this resulted in several options for and versions of constraints.

Variations to the two main scenarios are also tested to see what impact they could have on the maximum GVA and employment opportunities. These variations are closure of the 0-3nm area to trawlers and a requirement to land all nephrops product whole.

The effectiveness of an optimisation model declines if parameters are subject to uncertainty; and several key parameters required to calculate GVA opportunity are subject to uncertainty. Uncertainty also affects the calculation of employment, but the risk is lessened due to reduced exposure to uncertain parameters.

**Maximum GVA**

It could be assumed that the fleet that can provide the maximum GVA within the constraints will be allowed to expand as far as possible, followed by the next fleet and so on. However, it is not quite that straightforward as fleets have different catchability in different spatial areas and therefore different combinations of fleet activity across métiers can result in higher total GVA. This means that the model undertakes a complex reallocation from fleet to fleet, including from creel fleet to creel fleet and trawl fleet to trawl fleet.
The model identifies two potential opportunities to increase GVA:

- Under scenario 1, reallocation of fishing opportunity and relocation of activity has a maximum additional GVA opportunity of nearly £14 million arising from improvements in the GVA of some trawl and all creel fleet segments. The model achieves this through a complex mix of restructuring and relocation of the fleet, which does increase uncertainty in the feasibility of the result. Almost half of the potential GVA improvement is a result of a ten-fold increase in the Firth of Clyde 10-12m fleet segment, with vessel numbers increasing from 7 to 69. Furthermore, the GVA is dependent on existing fleet segments increasing average days at sea, by quite a significant number of days in some fleet segments. If vessel businesses cannot increase days at sea and the Firth of Clyde increase is infeasible, maximum additional GVA could be £5 million.

- A move to landing only whole nephrops provides a maximum additional GVA opportunity of £42 million. In this scenario variation there is less requirement for reallocation of fishing opportunity and relocation of activity. The increase in this scenario variation largely accrues to the trawl fleet.

Neither of the potential opportunities to improve GVA take into consideration the ability of the market to adapt to changes in supply and price. Furthermore, GVA in a fleet segment can be highly variable from one year to the next. The selection of a different baseline year could have a notable impact on the ‘optimal’ solution under a GVA maximisation objective.

Maximum employment

The findings of scenario 2, which sought to maximise employment, suggest that the current Scottish nephrops fleet is already achieving employment, that given the likely challenges of achieving maximum opportunity, could be considered to be close to optimum. The model estimates maximum employment to be 1,428 FTEs and the fleet in 2017 employed 1,264 FTEs. Whilst the model does undertake fleet restructuring to achieve the maximum employment there is a question over whether such substantial intervention would be worth it in order to secure a 10% increase in employment. Furthermore, the increase in employment would be achieved with a slight negative effect on total GVA and, perhaps more importantly, the costs of change are not considered in the model.

Conclusions

The study asks a question ‘can optimisation modelling be used in the Scottish nephrops fishing industry, and if so, what can it tell us?’

The first half of the question is ‘Can optimisation modelling be used in the Scottish nephrops fishing industry?’ The answer is yes, but there are challenges, each impacting on the next

Data challenges – Optimisation calculations are heavily reliant on quality of data and small adjustments can have a substantial impact on the solution identified. The data used for the study was not collected to be used in as detailed a spatial analysis as undertaken and existing datasets are incomplete and not easily combined. Therefore, the analysis required substantial data modification and the application of assumptions which increases uncertainty within the analysis.

Modelling challenges – A wide range of variables influence activity in the real world and modelling must simplify these. Furthermore, the design of the model requires the application of constraints and a somewhat subjective approach to achieving a balance between freedom for the model to explore opportunity and constraining the model’s calculations to explore interesting yet reasonable scenarios. Furthermore, the optimisation to maximise GVA is highly sensitive to profit which is at
the mercy of a relatively high number of parameters (catchability, price and costs) and data quality in each parameter will have an impact. Furthermore, price, landings and costs in the fishing industry tend to be variable from one year to the next, and this would occur even if perfect data existed. With greater sensitivity to a higher number of parameters, and differences between fleet segments, it is possible that a GVA optimisation of 2018 data or 2019 data could lead to notably different solutions. The employment optimisation is subject to fewer uncertain parameters.

**Interpretation of results** – The optimisation testing provides a point-based solution which suggests if you do X you get Y. In reality, the interplay of variables including, but not limited to, human processes, environmental conditions and economics, means it is unlikely any restructuring of the industry would lead industry near to the maximum point identified. Both the GVA and employment scenarios identify a calculated maximum which assumes that all actors will work without resistance to achieve the maximum and that the proposed changes are 100% achievable and cost neutral to achieve. However, the nature of optimisation modelling means that the maximum identified is unlikely to be achievable in the real world where a range of internal and external factors influence business decision-making. Furthermore, the costs associated with restructuring or relocating the fleet could be significant and these costs are not assessed in the model. The capacity of the supply chain to absorb a shift in product mix is also not considered. Therefore, optimisation modelling outputs are best used as one source of information in a wider evidence base.

The second half of the question asks, ‘what can optimisation modelling tell us?’ Despite the challenges summarised above, the exploration of optimisation modelling in the nephrops fishing industry has provided new information.

**A new analysis of inshore activity** - The industry mapping has produced a wealth of information at a relatively small spatial level. Whilst some assumptions have been required, the analysis provides a new lens through which to view and improve understanding of the Scottish nephrops fleet, particularly in the most active spatial areas in the inshore areas West of Scotland. Furthermore, the methodologies used to address data weaknesses could be replicated by others attempting novel analysis with existing data sets.

**Identification of opportunities** - The value of the model lies in examining the distance between the baseline and modelled opportunities. By supplying answers to specific questions, the model can be used to help inform discussion around what objectives are desirable and the issues and conditions that may be hindering a more optimal outcome for Scotland. However, it is recommended that the detail of the findings is used with caution and best treated as indicative of the existence of opportunity rather than as a potential target, and not as an estimation of impact from change.

**Conclusions**

The information produced for the industry mapping has been used to populate an optimisation model. The model has tested several scenarios to produce a view of the best outcomes available to Scotland under specified objectives, should there be relative freedom to change the operation of the Scottish fleet. All models are a simplification of reality that incorporates uncertainty. Furthermore, an optimisation model will pursue one more FTE or one more pound of GVA if it is available, regardless of the disruption required to achieve it. Model outputs are best used alongside information which adds more depth of understanding and helps to validate or refute model findings.

It is also vital that all interested parties understand that the level of detail produced has been achieved with compromises that result in some uncertainty in the industry mapping, which has a knock-on effect for the optimisation modelling. The compromises were necessary due to the nature
and quality of available data. A reduction in uncertainty can only be achieved through improved data or undertaking the analysis across multiple years to mitigate against annual variation.

This is not a policy appraisal and if changes are desired in certain areas then more work would be required to consider the impact and costs of attempting a move towards a more optimal outcome under either economic objective tested or an alternative objective.
1 Introduction

Sandfish Associates was commissioned by the Scottish Government to undertake an exploration of optimisation modelling in the Scottish nephrops fleet.

1.1 Context

Nephrops is Scotland’s second most financially valuable caught seafood species. In 2017, Scottish vessels landed 21,692 tonnes of nephrops with a quayside value of £73 million. The fishing vessels that catch nephrops are diverse in terms of gear, size, location and business model, and the product landed goes into three distinct supply chains: live, frozen/chilled whole and tailed. In general, creel catch serves the live market and trawled catch serves the frozen/chilled whole and tailed markets, although there are some exceptions.

Approximately 42% of live weight landings of nephrops by the Scottish fleets is exported, mainly to EU countries. Scottish exports are a combination of approximately 35% live and 65% frozen/chilled nephrops (source SFF17171). At a global level, Scotland is a key supplier of nephrops. In 2017, the Scottish fleet landed approximately 38% of the global supply of nephrops (source FAO2).

Existing datasets allow a good understanding of nephrops fleet activity at the ICES rectangle level and a good understanding of the economic performance of the fleet. However, the Scottish Government has questions around the activity of the fleet at a spatial level below ICES rectangle level and whether the nephrops resource is being utilised to generate the best economic return for Scotland.

1.2 Purpose of the study

The key question for the study is ‘can optimisation modelling be used in the Scottish nephrops fishing industry, and if so, what can it tell us?’

The study required:

- creation of a baseline of data on fleet activity at the most detailed spatial level that biology, activity and optimisation can be considered;
- development of a framework or model that would allow testing for an optimal solution; and
- testing of selected objective functions to explore distance between the baseline and optimal.

1.3 Approach

The study responds to the requirements using two different but related analyses:

- Industry mapping at sea. The industry mapping analysis establishes a baseline of nephrops fleet activity by manipulating the data available on the Scottish nephrops fleet to create a

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new and more detailed spatial view of fleet activity. This is supported by analysis which divides the fleet into fleet segments comprising similar vessel business and provides data on their economic performance.

- Optimisation modelling. A bespoke optimisation model was developed to explore what an optimal Scottish nephrops fleet might look like under different economic objectives. The main scenarios asked:
  - Scenario 1 – what is the maximum gross value added (GVA) that might be generated by the Scottish nephrops fleet; and
  - Scenario 2 – what is the maximum employment that might be generated by the Scottish nephrops fleet.

Variations to these scenarios are also tested to see what impact they could have on maximum GVA and employment. These variations are closure of the 0-3nm area to trawlers and a requirement to land all nephrops product whole.

This novel analysis of the Scottish nephrops fleet has been undertaken using available data on the fleet collected by the Scottish Government, and data on fleet economic performance collected and analysed by Seafish. However, it is noted that the data has limitations, and this is reflected in the reporting of findings and observations on the current value of optimisation modelling in the Scottish nephrops fleet.

1.4 Report content

This report presents information from all stages of the project:

- Chapter 2 reports on the fleet segmentation undertaken for the study;
- Chapter 3 describes the process of mapping the Scottish nephrops industry to spatial areas;
- Chapter 4 presents findings from the industry mapping;
- Chapter 5 describes the development of the optimisation model and key features of the model;
- Chapter 6 presents findings from the optimisation modelling;
- Chapter 7 provides conclusions and observations from the study team on the extent to which optimisation can be used in the Scottish nephrops fleet and what has been learned;
- Appendix A provides further detail on fleet segment activity not included in the 25 fleet segments detailed in the model;
- Appendix B details the key calculation constraints applied in the model; and
- Appendix C details the assumptions and allocation process required to match activity data to spatial areas.
2 Fleet segmentation

For the purpose of this study, the Scottish nephrops fleet is divided into fleet segments. The need to aggregate vessels into segments is two-fold. First is to set the level of analysis at a reasonable scale, and second, to be able to conduct the analysis at a level where data (particularly economic data) cannot be used to identify the performance of individual vessels. Vessels with the same combination of attributes are deemed similar. For this project, each vessel is allocated to a fleet segment according to the following characteristics:

- nationality (Scottish only);
- main gear used for fishing for nephrops (creel or trawl);
- length of vessel (<10m, 10-12m, 12-15m, 15-24m and 24m+);
- main fishing area as defined by landings value and functional unit (FU) (North Minch, South Minch, Firth of Clyde, Fladen Ground, Moray Firth and Firth of Forth); and
- dependency on nephrops, defined by the proportion of total landings value that was nephrops in 2017 (0-25%, 25-50% or 50%+).

Fleet segments with a dependency on nephrops of more than 25% of total landings value and containing more than four vessels are considered to be the main Scottish nephrops fleet segments. This identifies 25 separate nephrops fleet segments in Scotland and these are listed in Table 2-1 in order of fleet size.

The name of each fleet segment is derived as follows: main gear_size class_main FU_dependency on nephrops. For example, Creel_<10m_South Minch_>50% means that all vessels in that fleet segment use creel gear for the majority of catches, each vessel is under 10m in length, each vessel catches the largest proportion of its total landings value from the South Minch FU and nephrops represented more than 50% of the total value of all landings in 2017 for each vessel in the fleet segment. These 25 fleet segments landed approximately 85% of Scottish vessel nephrops landings in 2017. There are eight creel fleet segments, in three West of Scotland FUs, and 17 trawl fleet segments across six FUs.

Further detail on the fleet segments that catch nephrops but are not represented in the 25 fleet segments included in the analysis is provided in Appendix A.

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3 For the purposes of management and stock assessment, nephrops are split into a number of stocks or ICES ‘functional units’ (FUs) based on the discrete patches of mud which they inhabit.
Table 2-1: Scottish nephrops fleet segments

<table>
<thead>
<tr>
<th>Fleet segment</th>
<th>Number of vessels</th>
<th>Fleet segment</th>
<th>Number of vessels</th>
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<tr>
<td>Creel_&lt;10m_South Minch_&gt;50%</td>
<td>82</td>
<td>Trawl_15-24m_Fladen Ground_25-50%</td>
<td>11</td>
</tr>
<tr>
<td>Creel_&lt;10m_North Minch_&gt;50%</td>
<td>42</td>
<td>Creel_10-12m_North Minch_&gt;50%</td>
<td>11</td>
</tr>
<tr>
<td>Trawl_15-24m_Fladen Ground_&gt;50%</td>
<td>36</td>
<td>Creel_&lt;10m_South Minch_25-50%</td>
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</tr>
<tr>
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<td>26</td>
<td>Creel_&lt;10m_North Minch_25-50%</td>
<td>11</td>
</tr>
<tr>
<td>Trawl_15-24m_South Minch_&gt;50%</td>
<td>25</td>
<td>Trawl_15-24m_Firth of Forth_&gt;50%</td>
<td>9</td>
</tr>
<tr>
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<td>Trawl_12-15m_Firth of Forth_&gt;50%</td>
<td>8</td>
</tr>
<tr>
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<td>19</td>
<td>Trawl_12-15m_Moray Firth_&gt;50%</td>
<td>8</td>
</tr>
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<td>18</td>
<td>Trawl_10-12m_Firth of Clyde_&gt;50%</td>
<td>8</td>
</tr>
<tr>
<td>Trawl_&lt;10m_Moray Firth_&gt;50%</td>
<td>18</td>
<td>Trawl_12-15m_South Minch_&gt;50%</td>
<td>7</td>
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<td>Creel_10-12m_Firth of Clyde_&gt;50%</td>
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<td>12</td>
<td>Trawl_&lt;10m_North Minch_&gt;50%</td>
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<tr>
<td>Trawl_10-12m_Firth of Forth_&gt;50%</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 Industry mapping

The industry mapping analysis creates a new and more detailed spatial view of nephrops activity. There are two reasons for undertaking the industry mapping analysis:

- to establish a more complete and more detailed understanding of Scottish nephrops fishing activity at a relatively local spatial level; and
- to create a baseline dataset that feeds into the optimisation model so as to allow optimisation at a relatively local spatial level.

The industry mapping analysis produces five key outputs:

- initial definition of potential spatial areas to allow more localised analysis;
- allocation of known fishing time in 2017 to potential spatial areas;
- aggregation of areas to reduce complexity and number of potential spatial areas;
- allocation of catch and effort to potential spatial areas; and
- creation of a final activity database for 355 spatial areas around the Scottish coast.

Chapter 3 of the report presents an overview of the methods used to produce the outputs. Chapter 4 presents a selection of findings from the industry mapping exercise.

3.1 Initial definition of potential spatial areas

A key requirement of the study is to analyse the spatial activity of the Scottish nephrops fleet at a lower spatial level than has previously been undertaken. Most fisheries datasets are designed to capture activity data in ICES rectangles. ICES rectangles standardise the division of sea areas for statistical analysis. In the Scottish part of the UK EEZ, an ICES rectangle covers between 2800 km² (Northern part of the EEZ) and 3600 km² (southern part of the EEZ). To meet the requirements of the study, the industry mapping and subsequent modelling must be available at a smaller spatial level. For this purpose, new spatial areas are created.

Spatial areas divide the inshore waters into clearly defined areas to improve the resolution of the optimisation model. The following GIS databases were used in the industry mapping analysis:

- coastline buffers of several widths calculated from the mean high-water springs. Buffers have been produced by Marine Scotland for 1, 2, 3, 5, 6, 10 and 12 nautical miles and provided to the study team as a spatialised database (under the shapefile format). By construction, these coastline buffers are partially overlapped (the area covered by the 1nm buffer is included in the 2nm buffer);
- ICES rectangles;
- the delineation of nephrops FUs, which are aligned with ICES rectangles boundaries;
- estimated nephrops grounds derived either from the sediment data collected by the British Geological Survey (BGS) or from the analysis of historical VMS data (provided by Marine Scotland); and
- the UK EEZ.
The spatial analysis has been conducted with the opensource software Qgis. Maps are projected using the datum OSGB 1936 / British National Grid (EPSG:27700). Using other projections may generate different outcomes in terms of distance and area calculations.

The first step in the industry mapping analysis combines the various coastline buffers to create a set of multiple concentric ring buffers. By construction, these different ring buffers do not overlap, which is essential for the implementation of the model. Eight ring buffers are defined during this process:

- from the coastline to 1 nautical mile;
- between 1 and 2 nautical miles;
- between 2 and 3 nautical miles;
- between 3 and 5 nautical miles;
- between 5 and 6 nautical miles;
- between 6 and 10 nautical miles;
- between 10 and 12 nautical miles; and
- a last ring buffer is generated as the rest of the Scottish EEZ: from 12 nautical miles to the EEZ limit, allowing the model to fully represent the fishing area in which fishing vessels can target nephrops grounds.

These coastline buffer zones are then allocated to ICES rectangles to create localised buffer zones. As an example, the South Minch FU (FU12) is defined by nine ICES Rectangles. Combined with the concentric ring buffers, these nine rectangles contain a potential 170 spatial areas (Figure 3-1).

The length, and therefore the size, of the spatial area is determined by the geography of the coastline within the limits of the ICES rectangle.

Figure 3-1: Buffer zones and potential spatial areas in the South Minch Functional Unit
The definition of these buffer rings creates in some cases areas that are either very small or very narrow. Some of these areas are trapped inside other buffers, for example, the 10 to 12nm buffer in the northern part of the South Minch (orange triangle between South Uist and Skye in Figure 3-2). Although some of them may seem quite large (the triangle between South Uist and Skye has an area of 45 km$^2$), their location and shape generates an illogical spatial area. In order to address this, an additional variable has been created to reallocate each of these areas to a different buffer zone. For example, the orange triangle between South Uist and Skye, originally part of the 10 to 12nm buffer, is reallocated to the 6 to 10nm buffer.

The same logic applies to some parts of ring buffers partially trapped in narrow sea channels such as the centre part of the Sound of Sleat (green area in the North-eastern part of Figure 3-2), which is connected to the ring buffer between 1 and 2nm circling around Mainland Scotland. Several areas presenting a similar challenge are identified (some of them are represented in green in Figure 3-2). They are all treated according to the same process: the initial area is divided in 2 sub-areas, allowing reallocation of the problematic sub-area to another buffer ring.

Figure 3-2: Problematic areas in the South Minch Functional Unit

3.2 Allocation of fishing time to spatial areas

For each fishing trip in 2017 that caught nephrops, the total time spent fishing is allocated to the spatial areas fished by the vessel during the trip. However, defining when and where a vessel is fishing is challenging when there is no direct record of when and where vessels are fishing. Therefore, indirect information is used.

The data necessary to allocate fishing time to spatial area is not readily available at the level required for the analysis, therefore, the available datasets have to be manipulated, and assumptions applied. Furthermore, a different methodology for applying indirect information to estimate fishing
location is required for different fleet segments due to the different datasets available. Tailored methodologies were developed for under 10m vessels, 10-12m vessels and 12m+ vessels.

Allocation of under 10m vessel fishing time to spatial areas

FISH1 form data, which has been available since June 2016, provides a single latitude/longitude location point for the activity of each under 10m vessel per active week. Marine Scotland provided FISH1 data for 2017 to the study team. The FISH1 database contains some latitude/longitude locations that are on land or remote from expected nephrops fishing locations. These were excluded from the analysis.

To allocate FISH1 trip data to spatial areas in the model a methodology was developed which draws a 2nm bubble over each FISH1 location point (radius of 1nm from the FISH1 latitude/longitude point). The 2nm bubble identifies the spatial areas a vessel is assumed to have been active in during the trip, and the proportion of time it is assumed to have spent in each spatial area (see left). The estimation allows the total days at sea of each vessel per week to be allocated to spatial areas (see right). If the bubble crosses onto land, as shown on the left (15%), then the proportion of the bubble on-land, and its associated activity, is allocated to all other spatial areas (55%/(30%+55%) = 65%, see right). This methodology was used to identify the spatial areas fished by 317 under 10m vessels from 1,633 latitude/longitude positions in 2017. Only latitude/longitude points associated with trips where nephrops was caught were analysed.

Allocation of 12m+ vessel activity to spatial areas

The allocation of 12m+ vessel days at sea to spatial areas uses vessel monitoring system (VMS) information which transmits a latitude/longitude point at regular intervals from equipment on all vessels over 12m. VMS is the only automated system for identifying the location of fishing vessels and is only applied to vessels of 12m or longer. Marine Scotland provided a database detailing all positions recorded for 2017, with the detailed location (latitude/longitude), the time of transmission and the Voyage ID. No information is available on the instantaneous speed at the time of the transmission.

To allocate VMS activity to spatial areas, a methodology to identify where a vessel was fishing on a trip, as opposed to where it was steaming, was developed. For each trip, the distance between two subsequent positions has been calculated using the haversine formula\(^4\). This formula computes the great-circle distance between two VMS points on a sphere given their longitudes and latitudes. Associated with the time difference between the two VMS points, an average speed has been

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\(^4\) haversine function of the “pracma” package of the statistical software R
estimated for each position. The average speed calculation identified some inconsistent VMS points (average speed over 30 knots) and these were eliminated from the analysis.

It is assumed that a vessel estimated to be travelling at less than 3 knots is trawling. Therefore, VMS points with an estimated speed between 0.3 knots and 3 knots are considered to be locations where nephrops catch is taken. Each position is then matched with the spatial area it belongs to. This enables the identification of time spent fishing in the spatial areas.

VMS points considered to identify where nephrops catch is taken were compared to suitable nephrops habitats from BGS sediment data in the South Minch and the findings indicate that:

- a large share of the fishing activity as identified by VMS points is occurring inside the suitable nephrops habitats or very close to it; and
- there appears to be potential nephrops grounds not identified in the sediment data.

Allocation of 10-12m vessel activity to spatial areas

There are no datasets which systematically collect geographic information for 10-12m vessel activity below the ICES rectangle spatial level. The methodology to allocate the days at sea of 10-12m vessels to spatial areas applies the following proxies:

- the allocation of 10-12m creel vessel fishing time to spatial areas is based on under 10m creel location data derived from FISH1 data; and
- the allocation of 10-12m trawl vessel fishing time to spatial areas is derived from the over 12m trawler location data estimated from VMS data.

3.3 Aggregate potential spatial areas to reduce complexity

The combination of buffer zone (distance from coast) and ICES rectangle in the industry mapping analysis initially created 1,076 potential spatial areas. However, in order to support a Scottish-wide optimisation model to solve, aggregation was necessary. In each ICES rectangle there is often more than one coastline due to islands, or a continuous coastline that has been divided in two by an ICES rectangle boundary, this creates multiple buffer zones of the same distance from the coastline within a single ICES rectangle. Where more than one buffer zone of the same distance from a coastline exists, the areas have been aggregated to create one spatial area, i.e. three 0-1nm buffer zones in one ICES rectangle have been aggregated to create one 0-1nm spatial area. This has resulted in a maximum of eight spatial areas in each ICES rectangle. As a result, the fishing time calculated in the previous step has also been aggregated to a new set of potential spatial areas.

3.4 Allocation of catch and effort to spatial areas

The fourth output in the industry mapping process allocates all nephrops landings and vessel effort to a spatial area. The recorded landings dataset contains the complete landings and effort of fishing vessels by trip and ICES rectangle. The output from the previous task provided a disaggregation of fishing time per fishing trip to spatial areas. This task matches trip data from the recorded landings dataset to the trip data on time spent in different spatial areas. Catch and effort data is then

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5 A speed of less than 0.3 knots is assumed to be harbour activity.
allocated to different spatial areas according to the proportion of the fishing time spent in each spatial area per trip.

The underlying assumption is that productivity per distance fished is constant, which assumes that nephrops are evenly distributed for each fishing trip. This assumption does not mean that nephrops are evenly distributed around Scotland: the aggregation of all fishing trips is generating an estimated distribution of nephrops density in the different fishing grounds. This approach allows an allocation of trip activity to spatial area, which can be translated into estimated landings and effort levels for each spatial area.

However, the combination of the recorded landings dataset and the FISH1 and VMS data does not always produce a match. A trip recorded in the landings dataset may not be present in either the FISH1 or VMS data sets and vice versa. Where a direct match is not possible, assumptions have been applied to address the gaps. These assumptions are described in text below Figure 3-3.

Figure 3-3 summarises the process followed to merge the output from the previous task with data from the recorded landings dataset and generate a complete dataset on fishing activity by spatial area for inclusion in the model.

**Figure 3-3: Overview of process to allocate catch and effort to spatial areas**

- **Fishing time of all trips that caught nephrops** is allocated to spatial areas (source: output from previous task)
- **Catch and effort data for every vessel trip that caught nephrops in 2017** (source: recorded landings dataset)
- Catch and effort data per trip is disaggregated and allocated to spatial areas based on time spent in each spatial area
- Assumptions are applied to address gaps in fishing vessel trip time data
- All nephrops catch and effort is allocated to spatial areas
- A dataset of nephrops fishing activity by spatial area is prepared for input to the optimisation model (including further aggregation)
Exploration of optimisation modelling in the Scottish nephrops fleet

Gaps in fishing vessel trip time data

There are a significant number of records in the recorded landings dataset that cannot be matched to the latitude/longitude information from VMS and FISH1 datasets which results in the inability to directly link landings and effort to spatial areas. In the case of the VMS dataset there are missing voyage IDs and vessel RSS numbers. In the case of the FISH1 dataset not all trips have a latitude/longitude point recorded and not all under 10m trips are included.

The proportion of recorded nephrops landings that could readily be allocated to spatial areas is presented in Table 3-4. Almost half of the under 10m creel vessel landings of nephrops is allocated directly and 20% of under 10m trawl vessel nephrops landings is allocated directly. For the over 12m trawl vessels, 72% of landings are allocated directly based on VMS data. As previously stated, no geographic data is available for 10-12m vessels and therefore no initial allocation could be undertaken for these vessels.

Table 3-4: Total allocated and unallocated landings of nephrops by Scottish vessels in 2017 to spatial areas

<table>
<thead>
<tr>
<th></th>
<th>Total allocated landings of nephrops to spatial area based on latitude/longitude information</th>
<th>Total unallocated landings of nephrops to spatial area based on latitude/longitude information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under 10m vessels</td>
<td>439 tonnes</td>
<td>481 tonnes</td>
</tr>
<tr>
<td>10-12m vessels</td>
<td>-</td>
<td>509 tonnes</td>
</tr>
<tr>
<td>Over 12m vessels</td>
<td>65 tonnes</td>
<td>34 tonnes</td>
</tr>
<tr>
<td>Trawl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under 10m vessels</td>
<td>191 tonnes</td>
<td>1060 tonnes</td>
</tr>
<tr>
<td>10-12m vessels</td>
<td>-</td>
<td>1062 tonnes</td>
</tr>
<tr>
<td>Over 12m vessels</td>
<td>12,268 tonnes</td>
<td>4,653 tonnes</td>
</tr>
</tbody>
</table>

The trips that could not be readily allocated to spatial areas require a different methodology. The allocation of activity is informed by the activity of other vessels in the same fleet segment. The allocation calculates the average time vessels in the rest of the fleet segment spend per trip in the spatial area as a proportion of total time spent in the relevant ICES rectangle per trip. This average is then applied on a trip basis to the unallocated activity of vessels from the same fleet segment fishing in the same ICES rectangle. Where that is not possible, a second methodology was applied which incorporates data on average activity from more fleet segments that fish in the same areas. See Appendix C for detail on the allocation steps applied.

3.5 Baseline nephrops activity dataset for model

Once allocated to spatial areas, each trip is defined by its métier. The métiers fished in each trip are defined by spatial areas visited, gear used (creel, trawl, other static or other mobile) and target fishery (nephrops, crabs & lobsters, whitefish or other). Very low activity métiers have been aggregated to enable inclusion in a working model as extremely large datasets cannot be optimised. The métiers were aggregated as follows:

- métiers with fewer than 10 days of total fishing across all fleets have been aggregated to FU area; and
métiers with between 10 and 100 days have been aggregated to FU and buffer area, rather than spatial area which is ICES rectangle and buffer area.

This final phase of aggregation has resulted in 355 distinct spatial areas in the model where the Scottish nephrops fleet is active. These spatial areas are across 157 ICES rectangles, 85 of which are from within the 14 nephrops FUs included in the model around the UK.

Once the activity of all Scottish nephrops vessels is allocated to métiers the data is aggregated to create totals of catch by species, and effort in days at sea, for each fleet segment in each métier. The dataset required for the model is then complete and, in simplistic terms, operates using an average activity pattern per vessel per fleet segment in each métier.

3.6 Economic analysis

The economic analysis contained in the industry mapping analysis is informed by the landings dataset from the Scottish Government and the economic performance dataset from Seafish. Seafish provided the study with a bespoke analysis of its economic performance dataset for the 25 fleet segments identified in the Scottish nephrops fleet. For each fleet segment, information on the amount of nephrops landed, the price achieved and days at sea is collected by the Scottish Government and is expected to be 100% accurate. However, the economic performance dataset is dependent on a survey of vessel businesses to establish costs and profit. The process uses data from a sample of vessels to estimate economic performance for the whole fleet. This means that information on costs, profit and GVA data is subject to influence by the characteristics of survey respondents. The economic data is a key component of the baseline data.
4 Fleet segmentation and industry mapping findings

The main purpose of the industry mapping analysis is to create a dataset that could be input to the optimisation model. However, the industry mapping has also generated new information not previously available.

A selection of findings from the industry mapping analysis are presented in chapter 4. The findings demonstrate:

- hotspots of activity, i.e. areas of inshore waters where there is believed to be relatively high levels of activity. The information is presented by FU and gear type, not by fleet segment;
- distribution of activity for each fleet segment; and
- key indicators of economic performance for each fleet segment.

West of Scotland

The three nephrops FUs on the West of Scotland have considerable creel and trawl activity. However, the intensity of interaction between the gear types is greater within certain spatial areas in each FU. Please see Figure 4-1 (across two pages) for a visual representation of the information described below.

The description of activity by spatial area refers to ‘vessels using creel gear or trawl gear’ rather than creel or trawl fleet segments. This is because the analysis of activity considers fleet segment and gear type and on occasion a trawl fleet may use creel gear and vice versa.

In 2017, the areas of greatest interaction between gear types and relatively high levels of overall activity were:

- ICES rectangle 44E3 in the North Minch (see page 20 for map). The spatial areas within 5nm of the coast appear subject to the most intensive fishing and interaction between gear types. In this area vessels using creel gear operate for a notable proportion of days in the 3-5nm spatial area. In rectangle 45E4 (see page 20 for map) there is also significant creel and trawl activity, but vessels using trawl gear are largely active outside of 3nm and vessels using creel gear are largely active within 2nm of the coast (see North Minch graph on page 20).

- ICES rectangle 43E3 in the South Minch (see page 20 for map). The spatial areas within 2nm of the coast appear subject to the most intensive interaction between creel and trawl gear. Note that rectangles 44E3 (described in previous bullet point) and 43E3 in the Minches are adjacent to each other (see South Minch graph on page 20).

- ICES rectangle 40E4 in the Firth of Clyde (see page 20 for map). The spatial areas within 2nm of the coast appear subject to the most intensive fishing and interaction between creel and trawl (see Firth of Clyde graph on page 20).

North Sea

Although there is recorded creel activity in North Sea nephrops FUs, there are not enough nephrops creel vessels with which to create fleet segments of sufficient size for the analysis, i.e. a minimum of five vessels.
Similar to the West of Scotland, it is evident that nephrops fishing activity is not evenly distributed across a FU. In the Firth of Forth, rectangle 41E7, and in the Moray Firth, rectangle 44E6, report the largest amount of nephrops fishing activity within the respective FUs and around 50% of the nephrops fleet days at sea in these rectangles are estimated to be undertaken within 3nm of the Scottish coast. In the Fladen Ground, activity is more dispersed, but concentration is evident in four ICES rectangles to the South-west of the FU.

Please note that the scale of the y-axis is reduced in the Fladen Ground and Moray Firth graphs (page 22).

Economic data

The economic analysis presented in the tables to the right of the activity charts is presented by the FU of the fleet segments identified for this study. However, these fleet segments do not only operate in their ‘home’ FU and the economic analyses incorporate activity in other FUs and other sea areas. These tables contain a substantial amount of information which is not extracted for discussion here. However, as an indicator of scale of activity between fleet segments in different FUs, the analyses show that:

- North Minch fleet segments landed 2,413t of nephrops valued at £8.8 million. Approximately 7% of tonnage and 23% of nephrops value was landed by North Minch creel fleets;
- South Minch fleet segments landed 3,172t of nephrops valued at £12.7 million. Approximately 22% of tonnage and 35% of nephrops value was landed by South Minch creel fleets;
- Firth of Clyde fleet segments landed 4,217t of nephrops valued at £11.6 million. Approximately 5% of tonnage and 14% of nephrops value was landed by Firth of Clyde creel fleets;
- Fladen Ground fleet segments landed 6,231t of nephrops valued at £23.4 million;
- Moray Firth fleet segments landed 584t of nephrops valued at £2 million; and
- Firth of Forth fleet segments landed 2,152t of nephrops valued at £6.5 million.

The maps to the right of the economic performance tables shows the ICES rectangles within each FU.
Figure 4-1: Nephrops activity by gear and location and fleet segment economic data

**North Minch**

- **#vessels**: 64 (Creel), 31 (Trawl)
- **Ave. DAS per vessel**: 332 (Creel), 227 (Trawl)
- **Total FTEs**: 64 (Creel), 134 (Trawl)
- **Total revenue**: £2,679,943 (Creel), £8,025,922 (Trawl)
- **Total gross profit**: £569,348 (Creel), £575,551 (Trawl)
- **Total GVA**: £1,317,836 (Creel), £2,953,464 (Trawl)
- **Nephrops tonnage**: 351 (Creel), 2,062 (Trawl)
- **Total tonnage**: 601 (Creel), 2,554 (Trawl)
- **Nephrops value**: £2,063,149 (Creel), £6,775,419 (Trawl)
- **Total value**: £2,679,943 (Creel), £8,025,922 (Trawl)

**South Minch**

- **#vessels**: 112 (Creel), 32 (Trawl)
- **Ave. DAS per vessel**: 351 (Creel), 359 (Trawl)
- **Total FTEs**: 118 (Creel), 162 (Trawl)
- **Total revenue**: £5,377,269 (Creel), £9,466,102 (Trawl)
- **Total gross profit**: £1,223,882 (Creel), £1,391,223 (Trawl)
- **Total GVA**: £2,721,363 (Creel), £4,182,778 (Trawl)
- **Nephrops tonnage**: 712 (Creel), 2,460 (Trawl)
- **Total tonnage**: 1,064 (Creel), 4,423 (Trawl)
- **Nephrops value**: £4,504,384 (Creel), £8,227,475 (Trawl)
- **Total value**: £5,377,269 (Creel), £9,466,102 (Trawl)

**Firth of Clyde**

- **#vessels**: 20 (Creel), 63 (Trawl)
- **Ave. DAS per vessel**: 273 (Creel), 566 (Trawl)
- **Total FTEs**: 31 (Creel), 213 (Trawl)
- **Total revenue**: £1,738,256 (Creel), £10,287,372 (Trawl)
- **Total gross profit**: £467,764 (Creel), £1,716,663 (Trawl)
- **Total GVA**: £929,296 (Creel), £4,651,469 (Trawl)
- **Nephrops tonnage**: 231 (Creel), 3,986 (Trawl)
- **Total tonnage**: 273 (Creel), 4,178 (Trawl)
- **Nephrops value**: £1,614,129 (Creel), £10,035,228 (Trawl)
- **Total value**: £1,738,256 (Creel), £10,287,372 (Trawl)
Exploration of optimisation modelling in the Scottish nephrops fleet

<table>
<thead>
<tr>
<th>Region</th>
<th>Creel</th>
<th>Trawl</th>
<th>#vessels</th>
<th>Ave. DAS per vessel</th>
<th>Total FTEs</th>
<th>Total revenue</th>
<th>Total gross profit</th>
<th>Total GVA</th>
<th>Nephrops tonnage</th>
<th>Total tonnage</th>
<th>Nephrops value</th>
<th>Total value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fladen Ground</td>
<td></td>
<td></td>
<td>52</td>
<td>651</td>
<td>417</td>
<td>40,698,429</td>
<td>4,065,409</td>
<td>14,042,801</td>
<td>6,231</td>
<td>15,675</td>
<td>23,434,337</td>
<td>40,698,429</td>
</tr>
<tr>
<td>Moray Firth</td>
<td></td>
<td></td>
<td>26</td>
<td>243</td>
<td>46</td>
<td>2,992,971</td>
<td>568,788</td>
<td>1,248,317</td>
<td>584</td>
<td>1,027</td>
<td>2,035,193</td>
<td>2,992,971</td>
</tr>
<tr>
<td>Firth of Forth</td>
<td></td>
<td></td>
<td>42</td>
<td>548</td>
<td>79</td>
<td>6,733,295</td>
<td>1,031,027</td>
<td>2,658,295</td>
<td>2,152</td>
<td>2,350</td>
<td>6,478,057</td>
<td>6,733,295</td>
</tr>
</tbody>
</table>

Figure 4-1 continued
For those areas where activity is relatively high and interaction between creel and trawl gear appears most intense, an additional analysis is presented in the next pages and details estimated creel and trawl activity by spatial area and by fleet segment. The analysis shows how many different fleets, including fleets categorised as being mainly based in another FU, are active in the ICES rectangles with most interaction between gear types.

Please note, where a trawl fleet segment is shown under the creel gear section of the graph it is because one or more vessels categorised as a trawl vessel has reported using creel gear. The same applies when a creel fleet segment is shown as active under the trawl gear section of the graph. In most cases the level of activity is relatively low.

Please also note that although the Firth of Clyde may appear most vulnerable to conflict between creel and trawl, it is understood that there is an arrangement by which conflict is minimised due to segregation of the fleets by day of the week, with creel vessels only fishing on certain days and vice versa. This arrangement may influence the appearance of a high degree of interaction between creel and trawl gear types within 0-2nm of the coast in the Firth of Clyde.
North Minch (ICES rectangle 44E3, one of six ICES rectangles in North Minch)

In 2017, five fleet segments using creel gear were active in this area of the North Minch (ICES rectangle 44E3). This area is where the industry mapping indicates there is greatest interaction between creel and trawl gear in the North Minch. The active fleet segments using creel gear include three North Minch and one South Minch creel fleet segments and one South Minch trawl fleet. The most nephrops dependent under 10m creel fleet represented 48% of creel gear days in the area (Figure 4-2).

In 2017, 13 fleet segments using trawl gear were active in this area of the North Minch, however, 10 of these fleet segments, including one creel fleet segment, represented only 9% of total trawl gear days. The most active fleet was the 15-24m North Minch trawl fleet, followed by the 12-15m South Minch trawl fleet. The activity of South Minch trawl fleet segments in this area indicates its proximity to the South Minch FU.

Figure 4-2: Scottish nephrops fleet activity in North Minch ICES rectangle 44E3

In 2017, Scottish nephrops fleet segments spent 3,026 days in this area of the North Minch, 62% of these days were by vessels using creel gear, and 38% of days by vessels using trawl gear. Of total days, 68% are estimated to have been spent within 3nm of the coast. Approximately 85% of days at sea using creel gear and 41% of days at sea using trawl gear were within 3nm of the coast (Figure 4-3).

The days spent within 3nm of the coast are disaggregated to show creel and trawl activity in individual spatial areas (Figure 4-4). Estimates suggest 42% of total days were spent in the 0-1nm spatial area and vessels using creel gear represented 89% of these days. A further 17% of total days were in the 1-2nm area where vessels using creel gear represent 64% of the days. Ten percent of total days were in the 2-3nm area, where days at sea were evenly matched between creel gear (49%) and trawl gear (51%).

Figure 4-3: Overview of days at sea by gear in ICES rectangle 44E3, North Minch

Figure 4-4: Breakdown of days at sea by gear within 3nm of coast in ICES rectangle 44E3, North Minch
South Minch (ICES rectangle 43E3, one of nine ICES rectangles in South Minch)

In 2017, seven fleet segments using creel gear are believed to have been active in this area of the South Minch (ICES rectangle 43E3). This area is where the industry mapping indicates there is greatest interaction between creel and trawl gear in the South Minch. Active fleets using creel gear include three South Minch and three North Minch creel fleet segments and one South Minch trawl fleet. The under 10m South Minch creel fleet segment (>50%) is the largest Scottish fleet segment in the analysis in terms of vessel numbers, with 82 vessels and dominates creel activity in this area with almost 1,300 days at sea (Figure 4-5).

In 2017, 11 fleet segments using trawl gear are believed to have been active in this area. Eight of these fleet segments represented 11% of total trawl gear days. The most active fleet was the 15-24m South Minch trawl fleet, followed by the 15-24m North Minch fleet and the 12-15m South Minch trawl fleet. The activity of North Minch vessels in this area indicates proximity to the North Minch FU (Figure 4-5).

Figure 4-5: Scottish nephrops fleet activity in South Minch, ICES rectangle 43E3

In 2017, Scottish nephrops fleet segments spent 3,320 days in this area of the South Minch. Of the total days, 72% are estimated to have been within 3nm of the coast. Approximately 46% of days at sea using trawl gear and 93% of days at sea using creel gear were within 3nm of the coast (Figure 4-6).

The days spent within 3nm of the coast are disaggregated to show creel and trawl activity in individual spatial areas (Figure 4-7). Estimates suggest 44% of total days were spent in the 0-1nm spatial area and vessels using creel gear represented 80% of these days. A further 17% of total days were in the 1-2nm area and vessels using creel gear represent 59% of the days. Eleven percent of total days were in the 2-3nm area, where days at sea were evenly matched between vessels using creel gear (49%) and trawl gear (51%).

Figure 4-6: Overview of days at sea by gear, ICES rectangle 43E3, South Minch

Figure 4-7: Breakdown of days at sea by gear within 3nm of coast, ICES rectangle 43E3, South Minch
Firth of Clyde (ICES rectangle 40E4, one of four ICES rectangles in Firth of Clyde)

In 2017, five fleet segments using creel gear were active in this area of the Firth of Clyde (ICES rectangle 40E4). This area is where the industry mapping suggests there is greatest interaction between creel and trawl gear in the Firth of Clyde. Active fleets using creel gear include both Firth of Clyde creel fleet segments, one South Minch creel fleet and two Firth of Clyde trawl fleets. Both Firth of Clyde creel fleet segments are relatively equal, with approximately 1,000 days at sea each, and together represent 92% of all creel gear days at sea in the area (Figure 4-8).

In 2017, 11 fleet segments using trawl gear were active in this area of the Firth of Clyde, however, seven of these fleet segments represented 11% of total trawl gear days. The most active fleet was the 15-24m Firth of Clyde trawl fleet, fishing for almost 1,500 days in this area (Figure 4-8).

In 2017, Scottish nephrops fleet segments spent 5,862 days in this area of the Firth of Clyde (ICES rectangle 40E4). Of total days, 95% are estimated to have been spent within 3nm of the coast. Approximately 92% of days at sea using trawl gear and 100% of days at sea using creel gear were within 3nm of the coast (Figure 4-9).

The days spent within 3nm of the coast are disaggregated to show creel and trawl activity in individual spatial areas (Figure 4-10). Almost half of all days at sea (45%) is estimated to have been spent in the 0-1nm spatial area and vessels using creel gear represent 56% of the days. A further 38% of total days were in the 1-2nm area where vessels using creel gear represent 31% of the days. Twelve percent of total days were in the 2-3nm area, where trawl gear was dominant, representing 90% of days.
Distribution of fleet segment activity

There are 355 spatial areas in the model. The number and location of active spatial areas for each fleet segment in 2017 is shown below. Figure 4-11 does not indicate the number of vessels or time spent in each spatial area. The data shows that at least one vessel in all fleet segments visited more than one FU in 2017.

**Figure 4-11: Distribution of fleet segment activity by spatial area and FU, 2017**

| Creel_<10m_North Minch_>50% | Creel_<10m_North Minch_25-50% | Creel_10-12m_North Minch_>50% | Trawl_<10m_North Minch_>50% | Trawl_15-24m_North Minch_>50% | Creel_<10m_South Minch_>50% | Creel_<10m_South Minch_25-50% | Creel_10-12m_South Minch_>50% | Trawl_12-15m_South Minch_>50% | Trawl_15-24m_South Minch_>50% | Creel_<10m_Firth of Clyde_>50% | Creel_10-12m_Firth of Clyde_>50% | Trawl_<10m_Firth of Clyde_>50% | Trawl_10-12m_Firth of Clyde_>50% | Trawl_12-15m_Firth of Clyde_>50% | Trawl_15-24m_Firth of Clyde_>50% | Trawl_15-24m_Fladen ground_>50% | Trawl_15-24m_Fladen ground_25-50% | Trawl_>24m_Fladen ground_>50% | Trawl_<10m_Moray firth_>50% | Trawl_12-15m_Moray firth_>50% | Trawl_<10m_Firth of Forth_>50% | Trawl_10-12m_Firth of Forth_>50% | Trawl_12-15m_Firth of Forth_>50% | Trawl_15-24m_Firth of Forth_>50%

| North Minch | South Minch | Firth of Clyde | Fladen Ground | Moray Firth | Other FU/Other |
Gross value added (GVA)

One of the economic objectives selected for optimisation testing by the Scottish Government asks what might the maximum GVA of the Scottish nephrops fleet be. This section presents baseline information on the GVA of the Scottish nephrops fleet. The analysis of GVA is dependent on the economic performance dataset created and held by Seafish.

In 2017, the 25 Scottish nephrops fleet segments landed a total of 18,769t of nephrops. The value of these landings was over £65 million, which represented approximately 75% of the total income of £88 million for the fleets. The fleet segments generated an estimated £35 million of GVA, of which £17 million was generated by the West of Scotland fleet segments and £18 million by North Sea fleet segments. Of the GVA generated by the West of Scotland fleet segments, £5 million was generated by creel fleet segments and almost £12 million was generated by trawl fleet segments.

Seafish data for a six-year period, 2012 to 2017, was used to calculate GVA as a percentage of total income for each Scottish nephrops fleet segment to investigate consistency across different years. Figure 4-12 presents this information showing the distance between the lowest percentage and the highest percentage of GVA to revenue in the six-year period. For example, the first fleet shown on the graph Creel <10m Firth of Clyde (>50%) fleet segment generated GVA equivalent to 41% of its revenue in 2012 and a GVA equivalent to 59% of its revenue in 2017. The graph is designed to show the extent to which GVA as a percentage of revenue can vary from one year to the next.

The black dots show the GVA percentage in 2017, the baseline year for the industry mapping and modelling. Under the measure of GVA to total income, 2017 represented one of the better years for almost all fleet segments. What is notable is that although income declined for many creel fleets in 2017 due to a decline in the average price for landings, vessels were able to maintain a high GVA percentage by managing costs and therefore 2017 represented the highest percentage of GVA to total income for a number of creel fleets. There are exceptions to this, particularly the 10-12m creel fleet segments. For example, the 10-12m creel fleet in the North Minch reported its lowest percentage of GVA to revenue in 2017 across the six years.

Figure 4-12: GVA as percentage of revenue for Scottish nephrops fleet segments in 2017
Two of the 25 nephrops fleet segments did not exist in three or more of the six years. The over 24m Fladen Ground fleet was only recorded in 2012, 2012 and 2017, and the 12-15 Moray Firth fleet was only recorded in 2016 and 2017. The existence of a fleet segment requires a minimum of five vessels that each share key characteristics, including a certain degree of dependency on nephrops. In the years where these fleet segments are not included it can be assumed that this requirement was not met due to vessels having either higher income from other species or lower income from nephrops.

Employment

In 2017, the 25 Scottish nephrops fleet segments supported 1,264 full-time equivalent posts (FTEs). The West of Scotland fleet segments employed 721 FTEs and the North Sea fleet segments employed 542 FTEs. In the West of Scotland fleet segments, 213 FTEs were in creel fleet segments and 509 FTEs were in trawl fleet segments.

GVA and Employment

Figure 4-13 presents GVA per FTE for each fleet segment in 2017. This indicates how, and if, the two different indicators relate to each other and how different fleet segments compare. The analysis demonstrates some consistency around the Scottish average for all nephrops vessels of just over £28,000 GVA per FTE. Of the 25 fleet segments, 17 fleet segments are within approximately £5,000 of the Scottish average. The fleet with the weakest GVA per FTE is the 10-12m North Minch creel fleet, which performed poorly in its ratio of GVA to revenue in the GVA analysis above. The fleet with the strongest GVA per FTE in 2017 is the less nephrops dependent creel <10m fleet in the South Minch (25-50%).

Figure 4-13: GVA per FTE of Scottish nephrops fleet segments, compared to the average for all Scottish nephrops vessels, 2017

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6 Employment data is taken from Seafish estimates.
5 Development of optimisation model

The purpose of Chapter 5 is to provide an overview of what an optimisation model is and how the bespoke model for the study was developed.

5.1 Setting an objective for the model

The purpose of the model is to explore what might happen if all Scottish nephrops fleet activity was driven by a single objective. The two objectives specified by the Scottish Government for testing in the optimisation model are:

- Scenario 1 – what might the maximum GVA of the Scottish nephrops fleet be; and
- Scenario 2 – what might the maximum employment in the Scottish nephrops fleet be.

Each objective is tested in a separate analysis.

5.2 Introduction to modelling

To understand the findings of the optimisation modelling it is important to have some understanding of the operation of the model.

A model is a simplification of reality. Optimisation modelling is the application of a mathematical model in order to explore the nature and scale of an opportunity or problem.

Optimisation modelling shows what might happen if all assets, in this case fishing vessels, are used to work towards a single objective. Unless constrained, an optimisation model will be as disruptive as it is allowed to be in the pursuit of an objective, it does not differentiate between a £1 million improvement or a £1 improvement, it pursues all opportunities for improvement equally. Furthermore, it assumes that all available avenues for improvement are equally reasonable and achievable.

An unrestricted model would identify the activity that best achieves the objective and direct all other activity to replicate it regardless of whether or not this is realistic. For example, if the South Minch under 10m creel fleet is best able to achieve the objective from a specific pattern of activity, a model without sufficient restrictions would direct all Scottish nephrops vessels to the same area, replicating the same business model to undertake the same activity with the aim of maximising the objective.

Constraints are a tool used to increase realism within a model recognising that complete freedom to optimise against a single objective is unrealistic. For example, constraints can recognise that fishing possibilities in an area are limited by stock size; and that there are barriers to change such as the business owner being committed to a particular geographic area meaning the fleet is not fully mobile and able to relocate. However, as the number of constraints included in the model increase, the freedom to explore the opportunity declines and the model becomes a simplification of the current position (Figure 5-1).

Constraints therefore help to reflect the reality that business decision-making is not based solely on a single goal such as maximising GVA or maximising employment but instead that decision-making is ‘constrained’ by a range of external factors that may be environmental, economic or social, and factors internal to the business such as the values of the business owner/manager or the capacity to invest in different opportunities.
The constraints which have been applied in the nephrops optimisation model:

- are considered to present a useful balance that allows freedom to explore the pursuit of a single objective within a somewhat constrained environment;
- take into account data constraints; and
- can be implemented within the technical constraints of an optimisation model of this size and complexity.

For the reasons outlined above the results of all modelling exercises should be considered indicative and informative rather than definitive or directive. Furthermore, assumptions have been used to address data deficiencies and these assumptions could have a substantial impact on the findings.

As stated above, optimisation modelling is a simplification of reality and uses past behaviour to identify the maximum opportunity that may be available if a single objective is pursued. Whilst the model developed for the study does detail the structural and operational changes required to achieve the calculated maximum, the study does not consider whether optimisation of performance, or changes to the fleet, in pursuit of a single objective is achievable or desirable.

5.3 Model structure

The bioeconomic model developed is described in Figure 5-2. As shown, the fishing fleets and their activity are linked to the nephrops stocks and other external factors. Essentially, four modules link together to describe the fisheries modelled: production, economy, biology and policy. In each module the key components and their relationships are indicated with dimensions of fleet segment (f), nephrops stock (s) and métier (m). The model describes a yearly optimisation (t).

The two key endogenous variables that drive the calculations in the model are numbers of vessels by fleets and average days at sea by fleet and métier. That is, with values provided for these variables all other variables and indicators can be calculated.
The economy module and the calculation of fleet performance is consistent with that used by Seafish in their annual assessment of fleet performance of the UK fishing fleets and in the Annual Economic Report published by the EU’s Scientific, Technical and Economic Committee for Fisheries (STECF).

5.4 Constraints

The constraints applied in the nephrops optimisation model have been divided into two distinct types:

- calculation constraints – calculation constraints define the relationship between two or more variables; and
- restriction constraints – create a bound (minimum and/or maximum limit) on a variable.

Calculation constraints define the relationship between two or more variables, tend to have fewer options for their application and are expected to be subject to less uncertainty or debate. In the model structure (Figure 5-2), the variables indicated by the “endogenous variables” and “calculated indicators” boxes are defined by the calculation constraints. An example of a calculation constraint is that fishing mortality of a nephrops stock by a fleet in a métier equals catchability of nephrops in the métier multiplied by the effort expended in the métier by the fleet segment. See Appendix B for further examples of calculation constraints.

Restriction constraints create bounds, or limits, on variables. Restriction constraints limit change. A restriction constraint is applied to restrict the freedom of the model and introduce greater realism in its function. Restriction constraints have multiple options for the limit which is set and therefore may generate more debate, including whether a particular restriction constraint should be applied at all or whether additional or different restriction constraints should be included.
### Table 5-1: Restriction constraints in the model

<table>
<thead>
<tr>
<th>Name</th>
<th>Focus</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch constraint</td>
<td>Spatial area</td>
<td>Total nephrops landings in a spatial area cannot exceed total 2017 landings from the same area</td>
</tr>
<tr>
<td>Effort constraint 1</td>
<td>Functional unit and fleet segment</td>
<td>Proportion of a fleet segment’s total kWdas spent in its ‘home’ FU cannot be reduced by more than 10 percentage points</td>
</tr>
<tr>
<td>Effort constraint 2</td>
<td>Fleet segment per vessel</td>
<td>Maximum DAS for a fleet segment = the highest DAS for the fleet segment type in 2017 + 10%</td>
</tr>
<tr>
<td>Effort constraint 3</td>
<td>Fleet segment and métier</td>
<td>A fleet segment’s activity in a low activity métier (≤1% of DAS) in 2017 cannot be increased</td>
</tr>
<tr>
<td>Effort constraint 4</td>
<td>Métier</td>
<td>Total kWdas in non-nephrops métiers [where other species dominate] cannot increase. [Also for very low activity métiers]</td>
</tr>
<tr>
<td>Effort constraint 5</td>
<td>Fleet segment and métier</td>
<td>A fleet segment cannot fish in a métier it did not fish in 2017</td>
</tr>
<tr>
<td>Gross profit constraint</td>
<td>Fleet segment</td>
<td>Gross profit of a fleet segment must be positive (≥£0)</td>
</tr>
</tbody>
</table>

The restriction constraints summarised in the table above are described below in more detail.

- **Catch constraint** - the catch constraint limits the total nephrops catch in a spatial area to the catch taken in 2017. The catch of nephrops in a spatial area (i.e. rectangle and buffer, e.g. 43E4_0-1nm) cannot exceed the total catch of nephrops in that spatial area in 2017.

- **Effort constraint 1** - a location constraint is included that means fleet segments cannot reduce the proportion of total days at sea they spend in their main FU by more than 10 percentage points. If the total days at sea increases or decreases, the use of a proportion does not unduly limit change. Whilst this does constrain wholesale relocation of a fleet segment, there is no limit on new vessels being added to any fleet segment to take advantage of opportunities which arise.

- **Effort constraint 2** - this effort constraint limits the average days at sea per vessel. The vessels in each fleet segment can increase their average days at sea to a maximum number of days. The maximum number has been calculated using the highest number of days at sea in 2017 for the fleet segment type (vessel size and gear) in Scotland days at sea plus 10%. The impact on FTEs has been checked to ensure such an increase does not create an unreasonable impact for vessels which employ less than 1 FTE to avoid a situation when a one-person business moves to 1.5 FTE. The current and maximum days at sea for each fleet segment are shown in Table 5-2. This constraint assumes that a fleet segment can increase its activity without requiring additional vessels. Furthermore, the ability to increase activity without a requirement for further vessels means that new opportunities can be more profitable. A sensitivity analysis is used to test what would happen if this flexibility is not available.

- **Effort constraint 3** - this effort constraint limits expansion in very low activity métiers. If a fleet segment fished for less than or equal to 1% of its days at sea in a métier in the baseline, the maximum number of days that it can fish is set equal to the baseline days for that métier. For example, if an average vessel in a fleet segment fishes for 100 days per year then if there is any métier that it fishes for less than or equal to 1 day then it cannot increase activity in that métier in the model.

- **Effort constraint 4** - this effort constraint for so-called “non-nephrops” métiers limits the kWdas of a métier to the level in 2017. “Non-nephrops” métiers are those métiers that have a higher value of species other than nephrops.

- **Effort constraint 5** – this effort constraint prevents fleet segments fishing in métiers where they have no activity in the baseline. For example, if a South Minch creel fleet has not fished in the spatial areas 5-6nm from the coast it is assumed that the fleet will not fish in that spatial area in the future and therefore the model cannot allocate activity for that fleet to that area.
• Gross profit constraint – the gross profit constraint means that vessels which remain active must be generating a gross profit of more than or equal to £0. This means that vessels in a fleet must have fishing revenue that is at least equal to the total fixed and variable costs (not including investment or depreciation costs) that an average vessel in the fleet can be expected to incur.

Table 5-2: Maximum days at sea per fleet segment as applied in constraint

<table>
<thead>
<tr>
<th>Fleet segment</th>
<th>Ave. DAS per vessel 2017</th>
<th>Max DAS in model</th>
<th>% increase allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creel &lt;10m Firth of Clyde &gt;50%</td>
<td>104</td>
<td>115</td>
<td>10%</td>
</tr>
<tr>
<td>Creel &lt;10m North Minch &gt;50%</td>
<td>74</td>
<td>115</td>
<td>56%</td>
</tr>
<tr>
<td>Creel &lt;10m North Minch 25-50%</td>
<td>89</td>
<td>115</td>
<td>29%</td>
</tr>
<tr>
<td>Creel &lt;10m South Minch &gt;50%</td>
<td>88</td>
<td>115</td>
<td>31%</td>
</tr>
<tr>
<td>Creel &lt;10m South Minch 25-50%</td>
<td>86</td>
<td>115</td>
<td>34%</td>
</tr>
<tr>
<td>Trawl &lt;10m Firth of Forth &gt;50%</td>
<td>80</td>
<td>115</td>
<td>44%</td>
</tr>
<tr>
<td>Trawl &lt;10m Moray Firth &gt;50%</td>
<td>91</td>
<td>115</td>
<td>27%</td>
</tr>
<tr>
<td>Trawl &lt;10m Firth of Clyde &gt;50%</td>
<td>106</td>
<td>115</td>
<td>9%</td>
</tr>
<tr>
<td>Trawl &lt;10m North Minch &gt;50%</td>
<td>55</td>
<td>115</td>
<td>110%</td>
</tr>
<tr>
<td>Creel 10-12m Firth of Clyde &gt;50%</td>
<td>169</td>
<td>195</td>
<td>15%</td>
</tr>
<tr>
<td>Creel 10-12m North Minch &gt;50%</td>
<td>169</td>
<td>195</td>
<td>15%</td>
</tr>
<tr>
<td>Creel 10-12m South Minch &gt;50%</td>
<td>178</td>
<td>195</td>
<td>10%</td>
</tr>
<tr>
<td>Trawl 10-12m Firth of Forth &gt;50%</td>
<td>137</td>
<td>150</td>
<td>9%</td>
</tr>
<tr>
<td>Trawl 10-12m Firth of Clyde &gt;50%</td>
<td>105</td>
<td>150</td>
<td>43%</td>
</tr>
<tr>
<td>Trawl 12-15m Firth of Forth &gt;50%</td>
<td>181</td>
<td>200</td>
<td>11%</td>
</tr>
<tr>
<td>Trawl 12-15m Moray Firth &gt;50%</td>
<td>152</td>
<td>200</td>
<td>32%</td>
</tr>
<tr>
<td>Trawl 12-15m Firth of Clyde &gt;50%</td>
<td>175</td>
<td>200</td>
<td>14%</td>
</tr>
<tr>
<td>Trawl 12-15m South Minch &gt;50%</td>
<td>171</td>
<td>200</td>
<td>17%</td>
</tr>
<tr>
<td>Trawl 15-24m Firth of Forth &gt;50%</td>
<td>150</td>
<td>230</td>
<td>53%</td>
</tr>
<tr>
<td>Trawl 15-24m Fladen Ground &gt;50%</td>
<td>211</td>
<td>230</td>
<td>9%</td>
</tr>
<tr>
<td>Trawl 15-24m Fladen Ground 25-50%</td>
<td>188</td>
<td>230</td>
<td>23%</td>
</tr>
<tr>
<td>Trawl 15-24m Firth of Clyde &gt;50%</td>
<td>180</td>
<td>230</td>
<td>28%</td>
</tr>
<tr>
<td>Trawl 15-24m North Minch &gt;50%</td>
<td>172</td>
<td>230</td>
<td>34%</td>
</tr>
<tr>
<td>Trawl 15-24m South Minch &gt;50%</td>
<td>188</td>
<td>230</td>
<td>22%</td>
</tr>
<tr>
<td>Trawl &gt;24m Fladen Ground &gt;50%</td>
<td>252</td>
<td>275</td>
<td>9%</td>
</tr>
</tbody>
</table>

The operational characteristics of a restriction constraint mean that different scenarios can be tested. Therefore, where less certainty exists around what constitutes a reasonable limit, different limits can be tested to assess the impact of different assumptions and variables. Two sensitivity analyses have been undertaken to test restriction constraints:

• A sensitivity analysis tests what would happen if maximum days at sea for a fleet segment vessel is equal to 2017 days at sea, instead of being allowed to increase as detailed above.

• A sensitivity analysis tests what would happen if an additional constraint is included which limits total kWdas in a spatial area to the total kWdas calculated for 2017.

Price is held constant in the model at the 2017 prices achieved by each fleet segment for each species. A third sensitivity analysis tests what would happen if quayside price for all nephrops landings reduces by 25%.

Chapter 5 has provided an outline description of the model and some of the key constraints applied.
Exploration of optimisation modelling in the Scottish nephrops fleet

6 Optimisation modelling

Chapter 6 presents headline results from the optimisation modelling. The chapter is structured as follows:

- key findings on the potential to maximise GVA and employment (FTE);
- an analysis that present findings from the two main scenarios;
- an analysis that shows how the model has altered the GVA and employment in each fleet segment in order to achieve the maximum identified under the two main scenarios;
- an analysis which compares the effect on GVA and employment of the scenario variations and the sensitivity analyses.

The main scenarios, scenario variations and sensitivity analyses included to test the model and identify the potential distance between the baseline and a potential maximum are:

Two main scenarios:
- scenario 1 – what is the maximum GVA for the Scottish nephrops fleet based on 2017 data; and
- scenario 2 – what is the maximum employment in the Scottish nephrops fleet based on 2017 data.

Two variations applied to both of the main scenarios (four scenario variations in total):
- variations 1a and 2a – what might the maximum opportunity (1a = GVA, 2a = employment) be if trawl gear is barred from spatial areas within 3nm of the coastline; and
- variations 1b and 2b – what might the maximum opportunity (1b = GVA, 2b = employment) be if all nephrops are landed whole.

Three sensitivity analyses applied to both of the main scenarios (six sensitivity analyses in total):
- sensitivity 1c and 2c – what is the potential effect on the maximum opportunity of an additional effort constraint at a spatial area level. The additional effort constraint limits kWdas in each spatial area to kWdas in 2017;
- sensitivity 1d and 2d – what is the potential effect on the maximum opportunity of a 25% price decrease for all nephrops landings; and
- sensitivity 1e and 2e – what is the potential effect on the maximum opportunity if the existing fleet cannot increase its average days at sea per vessel beyond those fished in 2017.

6.1 Key findings

Opportunities to increase GVA

Estimating the maximum GVA opportunity for the Scottish nephrops fleet in the optimisation model has identified two potential opportunities to improve GVA.

Reallocation of fishing opportunity and relocation of activity

The first opportunity to increase GVA is identified via reallocation of fishing opportunity between fleet segments, with a movement from trawl to creel, but also between creel and creel and trawl and trawl, and a relocation of activity to ensure those fleets with the best combination of profitability and catchability are preferred in areas where fishing opportunity exists for those fleets. Under scenario 1, the model estimates potential additional GVA benefit to Scotland from reallocation and relocation to be in the region of £14
Exploration of optimisation modelling in the Scottish nephrops fleet

million, but only if several existing fleet segments are prepared to increase their days at sea and, for some fleet segments, change location for a proportion of their activity. If existing vessels could not increase their days at sea, and new vessel start-ups are necessary to take advantage of potential opportunity, the GVA benefit would be limited to £9 million (see sensitivity 1e).

It should be noted that £6.4 million of the proposed GVA benefit under scenario 1 is allocated to the Firth of Clyde 10-12m creel fleet segment and would require this fleet segment to increase from seven to 69 vessels. If the expansion of the Firth of Clyde fleet was considered infeasible, the maximum additional GVA opportunity could be limited to approximately £7 million, or £5 million if current vessels cannot increase their days at sea to take advantage of the opportunity. The preference towards the Firth of Clyde 10-12m fleet segment may be driven by the price the fleet achieved for nephrops in 2017 and uncertainty around the location of the fleet’s fishing activity.

Transfer to higher value whole nephrops

The second opportunity to increase GVA is to move the trawl fleet away from landing tailed product. Analysis of price data from trawl fleets in Denmark indicates there may be a price penalty to the Scottish trawl fleet from its onboard processing of nephrops product (source: EUMOFA). However, further investigation is necessary to understand the influences on price in different countries as, biological, regulatory and supply chain conditions could all play a role. Under scenario 1, variation B, the model estimates the potential additional GVA benefit to Scotland if the fleet landed only whole nephrops to be in region of £42 million relative to the baseline, and an improvement of £28 million relative to scenario 1.

About the GVA scenario

Scenario 1, and its variations, suggest that there may be potential to increase GVA in the Scottish nephrops fleet through either a reallocation and relocation of nephrops activity or by moving to whole nephrops for all landings.

However, the GVA is the most sensitive scenario and modest changes in the baseline data could have a relatively big impact in the optimisation modelling. The sensitivity is created because the scenario is dependent on a high number of parameters. The formula is revenue minus variable costs and fixed costs plus crew share. Revenue is calculated from landings and price, and landings is calculated from catchability and effort. In addition to the complexity of the calculation there are two further challenges:

- many of the key parameters, for example price and landings, and therefore revenue and GVA, can be subject to substantial variations from year to year; and
- the data used to inform the key parameters is subject to a number of uncertainties, for example the estimation of catchability is based on estimated location data and the allocation of catch to spatial areas, and this informs total landings. Furthermore, some parameters, such as catchability are unlikely to be constant across the year due to seasonal fluctuations. For example if one fleet segment achieves a particularly good catch rate in a spatial area it only fishes in for part of the year, the model will assume that these favourable conditions can be achieved year round and will move the fleet segment into that area for more of the year, within the constraints of the model.

Opportunities to increase employment

Scenario 2 is designed to maximise employment in the Scottish nephrops fleet. The findings indicate that the current Scottish nephrops fleet is already achieving employment, that given challenges associated with pursuing a modelled maximum opportunity, can be considered to be close to optimum. The model estimates maximum employment to be 1,428 FTEs, which is 13% higher than the 1,264 FTEs employed by the fleet in 2017.
The calculation of FTE is based on average number of FTEs per vessel in the baseline multiplied by the number of vessels and adjusted for a change in the average days at sea of the fleet. For example, if in the baseline the average DAS of a vessel in a fleet is 200 but in the optimised scenario is 100, then half the FTEs for the average vessel are calculated to be required. The FTE optimisation is based on fewer parameters and there is less uncertainty in the parameters used therefore the FTE optimisation is considered likely to be more stable from one year to the next. However, similar to maximising GVA, relatively modest changes in the baseline could have a notable impact on the calculated maximum and how that maximum is achieved.

Despite the more modest difference between baseline and maximum employment, scenario 2 proposes quite substantive changes in employment at a fleet segment level in order to achieve the maximum. Scenario 2 perhaps best emphasises that an optimisation exercise will be as disruptive as the constraints included in the model allow in pursuit of the stated objective, even if that disruption achieves only £1 more of GVA or one more FTE. Therefore, while a modest opportunity to improve employment may exist, the route to achieving it may be highly disruptive.

The following suggestions are proposed as to why current employment may be relatively close to optimal employment:

- The local and rural nature of the majority of fishing businesses may lead to a high degree of community and social responsibility. The Scottish fleet may have evolved to support maximum employment; and/or

- The variable nature of the financial performance of fishing vessel businesses and their vulnerability to external forces may mean that business models are designed to maintain optimal employment rather than optimal profits. Drivers for this could include difficulties in finding and training new crew and therefore optimal employment is maintained in order for the business to be ready to take advantage of opportunities when they arise; and/or

- Safety is paramount in the fishing industry and maximum employment may be close to or equal to minimum employment from a safety perspective.

These suggestions are proposed as potential explanations, further analyses would be required to substantiate the true cause(s).

Conclusion on opportunities

The purpose of exploring optimisation in the Scottish nephrops fleet was to test what optimal might look like and how a calculated optimal may vary from the baseline in 2017. The challenge also required the optimisation to be undertaken at a relatively small localised spatial definition.

Under both the GVA and employment objectives, the scenarios indicate that improvements are possible, as would always be anticipated in an optimisation exercise. However, an optimisation model assumes that all actors will work without resistance to achieve the maximum possible under an economic objective; and that the proposed changes, within the constraints of the model, are 100% achievable.

With only one year of data, and the challenges experienced in developing the analysis, it is not without risk to draw any substantive conclusions from this exploration of optimisation modelling in the Scottish nephrops fleet. However, there are indicators that:

- Some fleet segments appear to have a better combination of catchability and price relative to their cost base and these fleets are favoured in an optimisation exercise. The 10-12m Firth of Clyde creel fleet is one notable example, but to a lesser degree so are other creel fleet segments and a number of trawl fleet segments.
The landing of a proportion of the catch as tails, rather than whole nephrops, appears to limit the GVA opportunity available to the trawl fleet segments and to Scotland as a whole. The Scottish nephrops fleet is operating with a level of employment close to the calculated maximum. However, none of the scenarios, or the variations, take into consideration:

- the ability or willingness of fleet segments to change their operations in order to achieve the maximum;
- the cost of change, including capital and variable costs such as fuel costs associated with relocation; or
- the ability of the market to adapt to changes in the product mix being landed.

The nature of optimisation modelling means that the maximum identified is unlikely to be achievable in the real world where a range of internal and external factors influence business decision-making; and the model does not take into account the barriers to change. Therefore, it is recommended that the detail of the findings is used with caution and best treated as indicative of the existence of opportunity rather than as a potential target, and not as an estimation of impact from change.

The remainder of Chapter 6 presents further detail on the main scenarios, the scenario variations and the sensitivity analyses.
6.2 Findings of scenarios 1 and 2 for Scottish nephrops fleet

The model has been used to test two scenarios. The first (S1) optimises nephrops fleet activity to maximise GVA, the second (S2) maximises employment (FTEs). The optimal scenarios are compared to the baseline nephrops fleet structure and activity.

**Scenario 1: Maximum GVA**

Scenario 1 is designed to maximise the GVA of the Scottish nephrops fleet. The findings suggest that maximum GVA could be £48 million, an increase of £14 million or 39% compared to 2017. The maximum GVA increase in the creel fleet is £10 million or 204%, and in the trawl fleet the maximum increase is over £3 million or 12%. The difference between maximum GVA and 2017 GVA for specific creel fleet segments varies from 1% (creel 10-12m South Minch) to 1220% (creel 10-12m Firth of Clyde). Overall the difference between the maximum GVA and 2017 GVA in the creel fleet is 40% in the South Minch, 127% in the North Minch and 796% in the Firth of Clyde. The most significant observed difference in the creel fleet is a substantial increase from 7 to a maximum of 69 vessels in the Firth of Clyde 10-12m creel fleet segment, and this accounts for £6.4m or 63% of the difference between 2017 GVA and maximum GVA.

The difference between GVA in 2017 and maximum GVA for trawl fleet segments varies from -92% (trawl 15-24m Firth of Clyde), to +285% (trawl under 10m North Minch). Maximum GVA in Scottish trawl fleets is higher in 9 of the 15 trawl fleet segments. The six fleet segments which experience a decline in GVA are the four larger Firth of Forth trawl fleet segments, the largest (24m+) Fladen Ground fleet segment and the largest Firth of Clyde trawl fleet. Figure 6-1 shows the effect of scenario 1 on the GVA of each of the 25 fleet segments.

**Scenario 2: Maximum employment**

Scenario 2 is designed to maximise employment. The maximum employment estimated in scenario 2 is 1,428 FTEs, representing a potential increase of 164 FTEs or 13% compared to 2017 employment. The model appears to maximise employment by increasing vessel numbers and reducing days at sea per vessel. The potential impact on GVA of maximising employment is a reduction of £39,000 compared to current GVA. The difference between maximum FTE and 2017 FTE is an increase 88 FTEs in the creel sector and an increase of 75 FTEs in the trawl sector. Scenario 2 indicates that the Scottish nephrops fleet is already operating close to an optimal employment scenario.

Figure 6-2 on the next page shows the effect of scenario 2 on the FTEs employed in each of the 25 nephrops fleet segments.
6.3 Scenarios 1 and 2 by fleet segment

Figure 6-1: Difference between baseline GVA and maximum GVA under scenario 1 (£’000s)

Figure 6-2: Difference between baseline employment and maximum employment under scenario 2 (FTEs)
Calculated GVA for each scenario, scenario variation and sensitivity analysis

Figure 6-3 presents the GVA in the baseline in 2017 and the calculated GVA under the two main scenarios and their respective variations and sensitivities.

The only scenario variation or sensitivity where GVA exceeds the maximum GVA calculated under the main GVA scenario (S1), is the variation to the maximum GVA scenario where all nephrops are landed whole (S1b) and the maximum FTE scenario with the variation that all nephrops are landed whole (S2b).

With the exception of the optimal FTE scenario which lands all nephrops whole (S2b), the maximisation of employment (all scenarios beginning with ‘S2’) has very little effect, or a negative effect, on the baseline GVA of the Scottish nephrops fleet.

Please see the beginning of chapter 6 for a description of the different scenario variations and sensitivity analyses.

Figure 6-3: Scottish nephrops fleet GVA in the baseline and under scenarios including variations and sensitivity analyses
Calculated employment for each scenario, scenario variation and sensitivity analysis

Figure 6-4 presents the employment in the baseline in 2017 and the calculated employment under the two main scenarios and their respective variations and sensitivities.

The only scenario variation or sensitivity where employment exceeds the maximum employment calculated under the main employment scenario (S2), is the scenario variation on maximum employment where all nephrops are landed whole (S2b) and the sensitivity analysis where additional effort constraints are applied (S2c).

The only scenario variation or sensitivity which has a negative effect on employment, relative to the baseline, is the scenario variation which excludes trawl vessels from all areas within 3nm of the coastline (S1a and S2a).

Please see the beginning of chapter 6 for a description of the different scenario variations and sensitivity analyses.
7 Conclusions and observations

The study asks a question ‘can optimisation modelling be used in the Scottish nephrops fishing industry, and if so, what can it tell us?’

The study team has undertaken two connected analyses in order to respond to the question:

- an industry mapping analysis to establish a more detailed spatial baseline of activity alongside economic analysis of a Scottish nephrops fleet divided into 25 fleet segments; and
- optimisation modelling to test what the maximum GVA and employment could be from the Scottish nephrops fleet.

7.1 Can it be done?

In response to the first part of the question ‘can optimisation modelling be used in the Scottish nephrops fishing industry?’ The answer is yes. However, there have been several challenges to overcome during the study and in understanding the findings including, but not limited to:

- data challenges;
- modelling challenges; and
- challenges associated with interpreting the results.

Data challenges

The greatest challenge for the study was the quality of data at the detailed spatial level. For example, industry mapping and optimisation modelling operating at an ICES rectangle level would be a relatively straightforward exercise as activity records, for example logbooks, have historically been collected at this spatial level. The complexity of the analysis and the model, and requirement for good quality data, increases as you ask and attempt to answer questions at a smaller spatial level.

Challenges in using existing datasets to create a disaggregated spatial analysis included data weaknesses, gaps and inconsistencies in the datasets. To overcome these challenges required significant management and manipulation of different datasets in order to establish a complete, albeit estimated spatial baseline. This inevitably introduces uncertainties into some of the parameters used in the model.

A further challenge is the diversity within the Scottish nephrops fleet. Simplification of the nephrops fleet so that it can be adequately represented in a model is challenging. The nephrops fleet is characterised by different gear types, different operating environments, different business models, different products and different markets. Furthermore, not all vessels can be included if they are particularly distinct from all other nephrops vessels, for example an over 12m creel vessel could not be included due to data confidentiality issues and it may have been interesting to see its impact on the optimisation.

Modelling challenges

Once a baseline dataset is ready, the next challenge is to design a model that will generate a solution under two different objectives. Once this is overcome, identification of appropriate constraints for the optimiser requires several cycles of development, testing and review. Constraints are necessary so as to avoid a solution that identifies a super-vessel taking all nephrops catch as the best outcome, or a solution that maximises employment but creates an unprofitable fleet. Selecting constraints requires constant balancing with the desire to ensure the model has freedom to explore so that the outcome is not unduly defined and limited by current practices.
Challenges associated with interpreting the results

Optimisation modelling is a useful tool to understand opportunity and constraints but is not a predictor and findings should not provide a target. Reality can never match a modelled outcome under a single objective because business decisions respond to many more factors and conditions.

The calculation of GVA is highly sensitive to several key parameters in the model due to the complexity of the calculation. In addition to this complexity:

- many of the key parameters, for example price and landings, and therefore revenue and GVA, can be subject to substantial variations from year to year; and
- the data used to inform the key parameters is subject to a number of uncertainties.

The model has been tested with one year of data from 2017. A different data year could produce a notably different maximum GVA due to the sensitivity of the GVA calculation to several parameters subject to uncertainty and annual variation. Price, landings, quota and costs vary from year to year in fisheries and this can have a significant effect on GVA. The ‘maximum’ GVA and the routes to achieve maximum GVA are unlikely to remain stable from one year to the next. Therefore, caution is advised in deriving too many conclusions from the specific figure provided for the estimated maximum GVA.

The maximum FTE scenario is subject to far fewer parameters and is therefore likely to be less sensitive to change from year to year.

Furthermore, the optimiser is sensitive and will provide all possible opportunity to the fleet that can generate £1 more GVA or one more FTE than the next fleet. Therefore, in some cases a substantial amount of disruption may be proposed for only limited total benefit.

Finally, it is vitally important to understand that the optimisation model and scenario results is not an analysis to estimate likely impact for Scotland. None of the scenarios, or scenario variations, take into consideration the potential barriers to change including, but not limited to:

- the ability or willingness of fleet segments to change their operations in order to achieve the maximum;
- the cost of change, including capital and variable costs such as fuel costs associated with relocation or the cost of new vessels, and the cost to fleet segments that could lose opportunity; and
- the ability of the market to adapt to changes in the product mix being landed whilst maintaining the price paid to vessels.

7.2 What can it tell us?

The second part of the question asks, ‘if optimisation can be used, what can it tell us?’

Although there are weaknesses in the spatial and economic data available, the industry mapping analysis is likely to be the best available source of information to improve understanding of the spatial distribution and performance of the nephrops fleet. Furthermore, the analysis could provide a useful source of information for impact analyses or spatial planning; and the analysis of activity hotspots may provide useful information for inshore management discussions.

The optimisation model and the scenarios, scenario variations and sensitivity analyses have presented an interesting set of results. The model estimates there may be opportunity to increase GVA by £14 million through a reallocation of fishing possibilities and a relocation of fleet segments. However, if the freedom to change is limited, for example because increasing the Firth of Clyde 10-12m creel fleet ten-fold and
increasing the days at sea fished by several fleets is not as easy as the maximum GVA scenario assumes, the additional maximum GVA opportunity may be closer to £5 million.

The model also estimates there could be a maximum opportunity to increase GVA by £42 million if all nephrops are landed whole. This scenario variation requires more limited operational change for the fleet than the main GVA scenario. However, there remains questions over how achievable the estimated maximum GVA might be.

The main scenario to maximise employment did identify a distance between maximum employment as calculated by the model and baseline employment in the Scottish nephrops fleet. However, the distance between the two is much less than the distance that exists between baseline and maximum GVA in the main GVA scenario.

The nature of optimisation modelling means that the maximum GVA and FTE identified is unlikely to reflect a likely outcome in the real world where a range of internal and external factors influence business decision-making. Business decision-making is not based solely on a single goal such as maximising GVA or maximising employment but instead decision-making is ‘constrained’ by a range of external factors that may be environmental, economic or social, and factors internal to the business such as the values of the business owner/manager or the capacity to invest in different opportunities.

In conclusion the industry mapping and optimisation model findings are as good as the assumptions implemented and the data used. In the nephrops optimisation model the data used is the best available and the assumptions well founded. However, the value is limited if in wider discussions the findings are not accompanied by contextual analyses which contribute greater realism around the operation of the fleet, the opportunities perceived to be available and the potential cost of change.

7.3 Additional observations

The following additional observations are offered by the study team.

- The optimisation model can be updated as conditions change to evaluate the impact on the potential opportunity available to Scotland.
- The model has optimised the performance of the nephrops fleet (GVA and FTE) at a Scotland level. An optimisation more sensitive to local conditions could be undertaken at a smaller geographic level, for example for one or two FUs. This could support analysis at a more granular spatial level, explore seasonal influences and offer additional understanding of local dynamics.
- The model presented optimises the baseline year providing a view of the optimal situation in that year. If the stock biomass of nephrops stocks were modelled year on year (for example, with forecasts of stock growth and catches taken) then TAC changes could be modelled and the optimisation of multiple years undertaken. However, the treatment of price and costs would require careful consideration.
- The effort measure used in the analysis (i.e. kw days at sea) may not be fully comparable across different gears (e.g. creel soak time and creel numbers versus trawl gear used). If improvements in data and knowledge on effort become available, then the model can be updated.
- Marine protected areas (MPAs) or other spatial management measures have not been modelled. However, if MPAs can be aligned with the spatial areas identified then it could be possible to model them.
- To develop a more robust understanding of the spatial distribution of fishing activity in inshore areas it may be beneficial to consider an alternative mechanism to the FISH1 form for the collection of data. The study team has experience of FisheriesApp from Vericatch which is used,
for example, in inshore fisheries in Indonesia and may provide an interesting model to investigate, if not already evaluated.

- The study team feels there are outstanding questions for Scotland if one aim is to increase fleet performance and GVA. In particular, it would be useful to explore the factors that determine quayside price for creel and trawl landed product in Scotland relative to trawl landed product in France and Denmark; and, investigate whether the scampi market is the only reason for low quayside prices for the Scottish trawl sector relative to other trawl sectors. Further, if the scampi market is the reason for relatively low quayside prices in Scotland:
  - does the scampi market drive the pattern of supply, effectively excluding alternative opportunities; or
  - does the lack of global demand for whole chilled/frozen nephrops create the scampi market?
Appendix A: Fleet segmentation data

As described in the report, a fleet segment is a group of vessels defined by nationality, main gear, size class, main fishing area and proportion of nephrops value landed. The threshold for number of vessels in a fleet segment is set to greater than or equal to 5. As described previously, the main source of activity data per vessel trip is the recorded landings dataset (i.e. Logbooks and FISH1 forms).

The full list of fleet segments with nephrops landings in 2017, along with the number of vessels present in each are presented in tables 1-3 that follow:

- Table 1 presents data for the 25 core fleets. These are fleets where we have enough vessels for the complete analysis;
- Table 2 presents data for fleets considered to contain ‘nephrops’ vessels, but each fleet segment has too few vessels for a full economic analysis. i.e. fewer than 5 vessels; and
- Table 3 presents data for fleets which catch nephrops but are considered to be ‘other’ fleets catching nephrops.

Note that Table 4 presents a summary of the number of vessels and landings value of the remaining fleet segments.

Table A1
Fleet segments with a dependency on nephrops of more than 25% of total landings value and containing more than four vessels are considered as the main nephrops fleets and presented in Table A1. This identifies 25 separate nephrops fleet segments in Scotland. These fleet segments are the focus of the optimisation exercise. The name of each fleet segment is derived as follows Gear_size class_main FU_dependency on nephrops, for example, Creel_<10m_South minch_>50% which means that all vessels in that fleet segment use creel gear the majority, if not all, of the time, each vessel is under 10m in length, each vessel catches the largest proportion of its total landings value from the South Minch FU and nephrops represented more than 50% of the total value of all landings in 2017 for each vessel in the fleet segment. It is worth noting that the 25 fleet segments indicated to be the main Scottish nephrops fleet segments cover approximately 85% of Scottish vessel nephrops landings. Given the scale of the optimisation model with these 25 fleet segments, all other fleet segments have not been included in the optimisation. Their activity could be assumed to remain constant.

Table A2
There are approximately 20 fleet segments that would qualify under all other measures for inclusion in the model as a nephrops fleet, but they have fewer than five vessels in each segment (Table A2). Where possible vessels were allocated to an appropriate fleet segment, but these remain unallocated. Economic data, which is provided by Seafish, cannot be presented for fleet segments with fewer than 5 vessels due to Seafish rules of data confidentiality. The 36 fleet segments in Table 2 landed 10% of the value nephrops landed by Scottish vessels in 2017. The challenges of fully including these fleet segments in the model, i.e. subject to all analyses, include, but are not limited to:

- A financial analysis cannot be undertaken as Seafish cannot give us financial data for these fleet segments;
- The number of fleet segments in Table 2 adds huge complexity to the optimisation (potentially another 36 fleet segments) to gain 10% of nephrops value;
- Attempts were made to group fleet segments to create large enough fleet segments to meet the Seafish criteria. However, the diversity of the fleet segments in terms of size, location and
dependency on nephrops, means that aggregated fleet segments would not provide more meaningful results than the approach taken.

There are 20 fleet segments with a nephrops dependency of over 50% in Table 2 and these vessels account for 7% of the total nephrops landed in Scotland in 2017.

Table A3
The 38 ‘other’ fleet segments catching some nephrops are presented in Table A3. These account for 3% of Scottish nephrops value (in the baseline).

**TABLE A1. Nephrops fleets with >=5 vessels**

<table>
<thead>
<tr>
<th>Fleet segment (Scottish vessels only)</th>
<th>#</th>
<th>Nephrops</th>
<th>Other species</th>
<th>%NEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTALS</td>
<td>442</td>
<td>64,738,992</td>
<td>22,867,090</td>
<td>74%</td>
</tr>
<tr>
<td>&gt;50% nephrops fleets</td>
<td>409</td>
<td>60,641,707</td>
<td>16,612,217</td>
<td>78%</td>
</tr>
<tr>
<td>25-50% nephrops fleets</td>
<td>33</td>
<td>4,097,285</td>
<td>6,254,873</td>
<td>40%</td>
</tr>
</tbody>
</table>

**TABLE A2. Nephrops fleets with <5 vessels**

<table>
<thead>
<tr>
<th>Fleet segment (Scottish vessels only)</th>
<th>#</th>
<th>Nephrops</th>
<th>Other species</th>
<th>%NEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTALS</td>
<td>67</td>
<td>7,817,058</td>
<td>6,021,692</td>
<td>56%</td>
</tr>
<tr>
<td>&gt;50% nephrops fleets</td>
<td>39</td>
<td>5,363,119</td>
<td>1,568,749</td>
<td>77%</td>
</tr>
<tr>
<td>25-50% nephrops fleets</td>
<td>28</td>
<td>2,453,938</td>
<td>4,452,944</td>
<td>36%</td>
</tr>
</tbody>
</table>
### TABLE A3. Other fleets catching nephrops

<table>
<thead>
<tr>
<th></th>
<th># Nephrops</th>
<th>Other species</th>
<th>%NEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTALS</td>
<td>1032</td>
<td>2,418,032</td>
<td>310,986,892</td>
</tr>
</tbody>
</table>

### TABLE A4. Non-nephrops fleets

<table>
<thead>
<tr>
<th></th>
<th># Nephrops</th>
<th>Other species</th>
<th>%NEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTALS</td>
<td>234</td>
<td>-</td>
<td>144,526,380</td>
</tr>
</tbody>
</table>
Appendix B: Key calculation constraints

- **EFFORT (in kWdas)** by the fleet segment in the métier = number of BOATS in the fleet segment * average DAYS at sea (DAS) by the fleet in the métier * engine power (kW) of the fleet
  
  - Note that as DAYS and BOATS changes in the optimisation, effort changes and therefore impacts the following calculation constraints. These are the key endogenous variables driving the model.

- **FISHING MORTALITY** of nephrops stock by the fleet in the métier = catchability of nephrops in the métier * EFFORT expended in the métier by the fleet segment
  
  - Note that catchability of nephrops is a calculated parameter based on the average catch rate of nephrops in the métier combined with a calibrated fishing technical power by the fleet. This ensures that differences in catches by fleet and métier reflect those observed in the baseline data.

- **CATCH (or YIELD)** of nephrops by the fleet in the métier = the FISHING MORTALITY of nephrops by the fleet in the métier * the nephrops stock biomass
  
  - Note that other species are included in the model using catch per unit effort. Also, the nephrops catch for other fleets not explicitly modelled is accounted for in the calculation of stock biomass.

- **LANDINGS** of whole and tails nephrops by the fleet in the métier = CATCH of nephrops by the fleet in the métier * proportion of whole/tails
  
  - Note that the live weight landings of nephrops by product type (e.g. whole and tails) is estimated using baseline proportions of whole and tails nephrops from landings and sales data.

- **REVENUE** by the fleet = the average price of the species by the fleet * LANDINGS of the species by the fleet in the métier

  - Note that the price in the model is exogenously determined from baseline data. On analysis there appears no direct link between price and level of landings as would be required to identify and use price flexibilities. As a result, it is assumed that constant prices best describe the short-term situation. If the impact of prices requires investigation, then sensitivity can be undertaken with appropriate assumptions input to the model regarding price data.

- **GROSS PROFIT** by the fleet = REVENUE by the fleet– CREW SHARE – VARIABLE COSTS – FIXED COSTS

  - Note that CREW SHARE is calculated from the average proportion of revenue used to pay crew * REVENUE; VARIABLE COSTS are the average fuel + other variable costs by the fleet per day * number of days at sea by the fleet; and FIXED COSTS are the average fixed costs by the fleet * the number of vessels in the fleet.

- **GROSS VALUE ADDED (GVA)** = GROSS PROFIT by the fleet + CREW SHARE

- **FULL TIME EMPLOYMENT (FTEs)** by fleet = number of BOATS * average #FTEs per vessel * (DAS/baseDAS)

  - Note that FTE is the average number of full-time equivalent crew on each boat, adjusted for the change in days at sea from the baseline (i.e. days at sea (DAS) divided by baseline days at sea (baseDAS)). This provides an indication of direct employment in the fleet.
Appendix C: Assumptions and allocation process for data gaps in the allocation of effort and catch to spatial area

The key challenge in the allocation of activity to SAs is to translate the data from a relatively high spatial level (i.e. ICES rectangle) to one that is much lower. The analysis presented has created a dataset that provides the time spent by vessels on each trip in the identified spatial areas. This stage takes the recorded landings dataset containing catch and effort data for all nephrops trips and merges it with the spatial area dataset to provide a complete trip-based activity dataset by spatial area. Given the spatial area data is created from VMS and FISH1 datasets, which by development contain >12m and <10m vessels respectively, it is known trips for 10-12m vessels are not represented and for <10m vessels are not complete. In these cases, assumptions are required to construct trip level spatial area data.

The recorded landings dataset can be joined to the VMS and FISH1 datasets by voyage identification. Note that the FISH1 voyage ID does not match that in the recorded landings dataset, therefore a match on vessel ID and date of landing (or start date) is used. Where there is a match for a voyage then those landings and effort in the recorded landings dataset can be allocated proportionally, based on proportion of time spent in the spatial areas provided by the spatial area analysis. An indication of number of voyages matching from the recorded landings dataset to VMS and FISH1 are presented in Table C1.

Table C1: Percentage of voyages matching between recorded landings and VMS or FISH1 datasets in 2017 broken down by vessel size class before spatial area analysis (Source: own analysis on recorded landings/VMS/FISH1 datasets)

<table>
<thead>
<tr>
<th></th>
<th>Under 10m</th>
<th>10-12m</th>
<th>Over 12m</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMS</td>
<td>-</td>
<td>-</td>
<td>97%</td>
</tr>
<tr>
<td>FISH1</td>
<td>54%</td>
<td>5%</td>
<td>-</td>
</tr>
</tbody>
</table>

If there is not a match, then the recorded landings are allocated based on average proportions of the spatial areas fished in the rectangle of the recorded landings:

- for FISH1 this is based on the average proportions calculated by gear in a rectangle;
- for VMS (as there are more matches) this is based on the average proportions for the fleet segment in the stated rectangle; and
- for the 10-12m creel and trawl fleets, as there is no coordinate data available, this is based on the proportions of activity in spatial areas of comparable fleets for under 10m creel vessels and either 12-15m or under 10m trawl vessel activity respectively.

The full allocation steps can be summarised as follows:

1. Aggregate all recorded landings data using trip level effort (DaysAtSea) and landings (t_livewt and TOTVALUE) by vessel ID, voyage ID, ICES rectangle, gear used and selected species.
2. Aggregate all recorded landings data to provide days at sea per voyage, by creating a trip level table of days at sea (i.e. voyage days) to enable an effort indicator to be maintained for lookup by trip.
3. Identify all “allocated voyages” by voyage ID in recorded landings to spatial areas, based on the spatial area analysis using FISH1 and VMS data. Where voyages match, a table of trip time shares (based on distance) is created in each spatial area (i.e. ICES rectangle and buffer)
4. List all voyages that don’t have spatial area(s) identified (“unallocated voyages”), based on the spatial area analysis using FISH1 and VMS data.
5. Match those unallocated voyages with averages by rectangle, gear and vessel length (FULL match), by rectangle and gear (PART match) and all other cases (Otherwise). For trip that do not have...
spatial areas identified from the spatial area analysis of FISH1 and VMS data, the average percentage of trips spent in ICES rectangles and buffers is applied. Note for 10-12m Creel and Trawl then the lookup in the FULL match is for <10m and 12-15m respectively. Note further that for creel, as matches are <10m then this is the same as a PART match.

6. Create full list of voyage data which is the result of combining the recorded landings dataset and the spatial area analysis is a complete trip level dataset identifying estimated fishing by spatial area for the species selected.

With the trip activity data from recorded landings merged with the trip spatial area data, then the model inputs can be created. The above data is aggregated by fleet, métier and buffer for input into the model.

The métier field in the above table is created according to the following rules

- Métier = (Gear+Fishery+Rectangle+Buffer] IF total days at sea in that métier > 100 DAS (example: TN38E401)
- Métier = (Gear+ Fishery +FU OR ICES sub-area+Buffer] IF total days at sea in that métier > 10 (and <= 100) DAS (Example: TrN_SM01)
- Métier = (Gear+ Fishery +FU OR ICES sub-area] otherwise (Example: TrN_NM OR TrN_4b)

Note that “Gear” is trawl, creel, other mobile or other static and “Fishery” is Nephrops, Crabs, Whitefish or Other