Evidence Gathering in Support of Sustainable Scottish Inshore Fisheries

Work Package 6 Final Report

Integrating Stock Management Considerations with Market Opportunities in the Scottish Inshore Fisheries Sector – a Pilot Study

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Integrating stock management considerations with market opportunities in the Scottish inshore fisheries sector – a pilot study

Final Report

Project code: SFS006SIF

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Commencement:	19/08/2014
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Total project costs: £37,000 + VAT

Staff inputs (days):

- Project director 50
- Senior consultant/advisor 20
- Research associate 25

Objectives and primary milestones

The **study purpose** (as specified in tender SFS006SIF, appended as annex 1) is:

To undertake a pilot project to assess the potential economic and associated benefits of establishing minimum market landing size (MMLS) in excess of minimum legal landing size (MLS) for Nephrops and velvet crab; and to evaluate if such intervention could be undertaken at a regional level.

The project had 4 **operational objectives**:

1. Within pilot areas and for identified species, determine the size distribution of individuals landed (above MLS) from stocks on a seasonal basis
2. Establish costs and returns associated with different sized specimens
3. Establish consequences of increasing MMLS through pilot economic assessments.
4. Evaluate the potential for increased MMLS as a tool for improved returns and fishery sustainability

Abstract

In June 2014, Hambrey Consulting successfully responded to a call for tenders for research to *undertake a pilot assessment of the potential economic and associated benefits of establishing minimum market landing size (MMLS) in excess of minimum legal landing size (MLS) for shellfish; and to evaluate if such an intervention could be undertaken at a regional level.*

The project was originally conceived as including 3 case studies, but the scope of the research led us to focus mainly on the trawl and creel fishery for *Nephrops* prosecuted by the fleet based in Skye and SW Ross. The basic framework for the assessment approach was to:

- Develop an economic profile of the case study area and its fishing fleet;
- Review and synthesise existing data on size profile of the catch, the factors that affect size, including costs associated with individual (vessel) actions or strategies to increase the size profile of the catch;
- Analyse market and market trends, and the prices for different sizes of product;
- Develop economic models of representative fishing enterprises, taking account of the relationships between costs and returns and the size profile of the catch;
- Use plausible scenarios to explore likely short term economic consequences of any changes in MMLS;
- Use yield and utility per recruit analysis to explore possible yield benefits associated with increased MMLS.

Main findings

1. Financial and yield per recruit modelling, suggests that introduction of a MMLS above the current 20mm carapace length (CL) MLS would have significant short and medium term negative effects on both costs and returns to trawler fishermen operating in the Skye and SW Ross case study area and the North Minch more generally.
2. For the creel sub-sector an increase in MMLS to around 33mm CL would have a largely neutral effect on costs and returns in the short term, but would generate significant medium term benefits arising from the increased yield and value associated with larger animals. In practice market demand and the size-selective nature of creels means that most of the creel fleet is already implementing a MMLS of between 34 mm and 40mm CL.
3. Increasing MMLS across the board for a mixed creel/trawl fishery to 25mm or 30mm CL is likely to generate substantial gains to the creel fishery and losses to the trawl fishery.
4. The analysis highlights the fundamentally different interests of the creel and trawl sub-sectors, and suggests that a greater degree of physical separation, ideally corresponding with (at least partially) subsidiary stocks, would allow for more rational and optimal fisheries management in line with both stock management and marketing strategic needs.
5. Preliminary analysis of (limited) data relating to velvet crabs suggests that there is a case for increasing MMLS to as much as 77mm for at least part of the year.

Contents

Acknowledgement

This report was prepared by Dr John Hambrey, with significant contributions also from Dr Paul Medley, Sue Evans, Crick Carlton, Carole Beaumont, and Tristan Southall. It is informed by many others, including fishermen and their representatives, traders, the staff of Marine Science Scotland, Marine Analytical Unit, harbourmasters and others. A full list of consultees is provided in Annex 1.

1 EXECUTIVE SUMMARY

1.1 This project

In June 2014, Hambrey Consulting successfully responded to a call for tenders for research on “Integrating stock management considerations with market opportunities in the Scottish inshore fisheries sector” – a pilot project under the broader European Fisheries Fund funded project: Evidence Gathering In Support of Sustainable Scottish Inshore Fisheries. This was one of 7 projects funded under the programme.

The objective of this study, as set down in the tender specification and modified slightly in the final contract, was:

> *To undertake a pilot assessment of the potential economic and associated benefits of establishing minimum market landing size in excess of minimum legal landing size for Nephrops and velvet crab; and to evaluate if such an intervention could be undertaken at a regional level.*

The rationale for the project is that

a. An increased minimum market landing size (MMLS) may lead to improvements in stock health and potential for increased yield or size profile of landings in the future; and
b. The price paid/kg for larger animals is higher than for smaller animals, and there may therefore be substantial increases in returns per kg landed, with potential for significantly increased returns for the industry as a whole.

1.2 Methodology

To maximize the benefits of the project, and to ensure that it was well informed, it was considered essential to engage local fishery interests (skippers and traders) so that a realistic understanding of fishing practice, production economics and market opportunities could be developed. In general this was successful, though some skippers were resistant to the idea of any changes in landing size, making engagement challenging.

The basic steps in the research were:

1. Develop an economic profile of case study area, and an understanding of the structure and economic contribution of the case study area fleet;
2. Review and synthesise existing data on size profile of the catch;
3. Seek an improved understanding of the factors that determine catch size profile, and in particular fishing technology and practice, from literature and industry sources;
4. Develop an understanding of any costs that may be associated with gear changes or individual (vessel) actions or strategies to increase the size profile of the catch;
5. Develop an understanding of the market and market trends, and the prices associated with different sizes of product;
6. Develop economic models of representative fishing enterprises, including relationships between fishing costs and any changes required to increase MMLS, and between returns and size profile of catch;
7. Using plausible scenarios for representative enterprises, and for the fleet as a whole, use the models to explore likely economic consequences of any changes in MMLS;
8. Using stock assessment techniques, explore the consequences in terms of possible future increases in yield from the fishery;

9. Discuss the overall costs and benefits, and the feasibility of introducing a MMLS at a regional level;
10. Discuss the utility of the overall approach in terms of informing improved inshore fisheries management.

Although the research began with three case study areas (Skye and SW Ross *Nephrops* trawl and creel fishery; South Uist and Barra velvet crab fishery; and Burghead/Inner Moray Firth trawl fishery, it was beyond the scope of the project to follow through the full process in all three areas; and Skye and SW Ross Trawl and Creel fishery for *Nephrops* was selected for the main focus of the study.

1.3 Main findings

Unless otherwise stated, the following refers to the Skye and SW Ross Case Study

Fishing enterprises and economic contribution

1. There is great diversity in the types of fishing enterprise in the case study area, especially within the creel sub-sector. While creel vessels are relatively standard (usually around 8m in length, 50-100KW, and 20-25 years old), there is a continuum of activity from just a few days at sea to more than 250. In this sense the creel fishery is fulfilling a range of social and economic functions including full time professional activity, through part time activity to supplement other part time income, to mainly recreational activity for pleasure/interest and a modest additional income to supplement, e.g. pensions or savings. The trawl fishery is more uniform, with a much smaller proportion of low activity vessels, reflecting the more substantial investment involved.
2. Total local employment as skipper or crew amounts to around 100 in the creel sector and 30-40 in the trawl sub-sector. Landed value of product amounts to around £2.9million in the creel sub-sector and £1.8m to the trawl sub-sector. We have not estimated shore based jobs or income, but these are likely to be significantly higher for the creel sector at local level. In local terms, and especially for the more isolated communities, these are significant figures.

Baseline costs and returns

3. Baseline costs and returns have been estimated using the Seafish economic performance database, modified as appropriate to reflect the particular characteristics of the local fleet and information from local skippers. This has proven surprisingly challenging. Many of the costs allocated to individual vessels in the Seafish economic performance database are estimates based on an average performance for the sub sector, rather than actual performance of the individual vessel (e.g. fuel consumption/day at sea is assumed to be the average for a sub-sector such as less than 10m pots and creels); maintenance costs are estimated as a standard proportion of fishing income, also based on the average for the sub-sector). The data does not allow for an analysis of how vessel financial performance is likely to vary with, for example, catch per unit effort – a key performance parameter likely to be affected by any change in MMLS.
4. For the purposes of this analysis we have therefore had to make significant assumptions, based on “benchmark” information in the Seafish database, coupled with information on the nature of the local fleet, and typical costs and production parameters derived from a wide variety of industry and research sources.
5. A further significant problem relates to the estimation of capital related costs (depreciation, interest/finance) which – while there are standard protocols – are

nonetheless estimated (or at least perceived) differently by different types of enterprise. Furthermore, these costs are not independent of gear and maintenance costs, since real depreciation will be much lower when more is spent on gear and maintenance. In practice depreciation is relatively low for most vessels, partly because of their age (typically 20-30 years) and partly because of regular gear replacements. Without a detailed understanding of depreciation, financing and maintenance regimes and their interaction, it is very difficult to understand the financial drivers influencing fishing patterns and behaviour.

6. Given these issues we have developed standard baseline models based on a range of sources and estimates. While these have been partly validated through discussions with individual fishermen, it would nonetheless be desirable to further validate the models with the industry in any follow up work.
7. It is clear from all the various sources however that costs and returns are highly variable, dependent on levels of activity (days at sea), capital and financing structure, age and condition of vessel, fishing skill, and marketing skill.
8. Our baseline models suggest reasonable returns to labour (average, skipper and crew) – around £250/day for active creelers, £90-160 for 8-12m trawlers, and £260 for larger visiting vessels (14-15m). This takes no account of any returns due to owners/capital.

Current fishing practice and catch size profile

9. Substantial information is available on these issues for both creel and trawl fleets from the work of Marine Scotland Science, various studies in support of MSC certifications for both creel and trawl fisheries, the research of Adey (2007), from fishermen, and from traders. Although data should also be available from Marine Scotland/MMO data on buyers and sellers transactions, this proved more difficult to access (for data protection reasons) than that direct from traders and fishermen.
10. The current regulated minimum landing size for *Nephrops* is 25mm carapace length (CL) on the east coast and 20mm CL on the west coast.
11. The catch profile (before discard) of the creel fleet normally includes very few prawns of less than 32mm CL – which is also the minimum marketable size for live langoustines. However, some creelers discard prawns of less than 40mm CL in line with demand from particular markets and traders, and some fit escape gaps specifically designed to allow prawns up to this size to escape.
12. For the trawl fishery the catch profile on average is generally of smaller animals, but nonetheless few (usually less than 5%) are caught of less than 20mm CL – the current minimum regulated landing size. However, around 20% are less than 25mm CL (regulated MLS on the east Coast) and around 50% less than 30mm CL.
13. These generalisations mask substantial variations. The size profile of the catch varies significantly for both trawl and creel according to location, depth, season, time of day, state of the tide and so on. Some of these differences are also related to the different behaviour of males (generally larger) and females. It is likely that a significant part of the variation in economic performance of different vessels relates to skills in understanding these variations, and matching fishery strategy to market demand.
14. Creel "soak time" (days the pot is left set) may also influence size and yield. It seems likely that - for a variety of behavioural reasons - a longer soak time will yield a larger prawn and/or more prawns, although there is no quantitative data to support this.
15. In the case of trawlers, there may also be effects related to the net design and mesh size (and there are significant variations within existing regulations), as well as trawling practice. Shorter, slower tows are likely to yield a higher quality product (more whole, undamaged prawns), with a higher proportion capable of surviving post capture. It may

also be the case that shorter or slower tows result in a larger size profile of catch, though there is no scientific data to support this.

16. A simple spreadsheet model has been developed that converts a live whole catch profile (numbers of prawns caught by size category as determined by historic scientific survey) to a landed product profile in terms of percentage by weight of the different commercial product categories, including whole prawns and tailed prawns. This allows for the estimation of the impact on landed product value (£/kg) of any changes in catch size profile arising from changes in fishing practice designed to reduce the catch of animals below an agreed MMLS.

Techniques and strategies to increase MMLS

17. In the creel fleet many fishers already use gear modifications (escape hatches) or fishing strategy (depth, substrate, location, season, soak time etc.) to achieve a catch predominantly larger than 40mm CL, and discard smaller live animals that may nonetheless be caught. It is likely that further modest increases in soak times and/or use of escape hatches or larger escape hatches could be used to further enhance the size profile were this considered desirable for market or stock health reasons.
18. In the case of trawls some fishers already use a shorter final tow to increase size and quality, and some occasionally market a small proportion as live. However the costs of implementing shorter tows more regularly is significant in terms of lost trawl time, and in most cases the benefits from a few live prawns are thought to be outweighed by the increased complexities of handling, possible investment in holding tanks and loss of what is usually the main catch destined for the tails market (one of the issues that can be directly explored with the models).
19. Substantial research has been undertaken on *Nephrops* trawl gear, primarily related to efforts to reduce whitefish bycatch, and some of this also addresses size selectivity with respect to *Nephrops*. There has also been some dedicated research undertaken to increase size selectivity of trawls, especially in Scandinavia, and to a lesser degree France, where a MLS above that used in the UK has been introduced. The vast majority of this research shows that gear changes designed to release smaller prawns are not particularly effective, and also tend to release larger prawns. This relates primarily to the relatively passive behaviour of prawns once within a net, and to their body shape which does not allow for easy size related release. Many trials have shown a very substantial reduction in overall catch - commonly up to 40%. However, there appear to be some opportunities for using a grid as used by some trawlers operating out of Brittany ("French grid") although data on its impact is limited, especially for the Scottish fishery. This warrants further research.

Market opportunities for larger prawns

The following refers to markets for *Nephrops* from Scotland generally. Specific opportunities for larger prawns for local markets within the case study area are limited and demand is largely met at present. More information on markets can be found in SIF WP05.

20. The market for *Nephrops* (referred to usually as prawn tails or (whole) langoustines by traders) has developed and evolved steadily over the last 60 odd years. The market for live prawns is a relatively recent phenomenon emerging in the late '80s and early 90s, to become a major sub-sector in recent years.
21. There are three main landed products: tails, roughly 95% of which is destined for the UK processed (scampi) market; whole fresh prawns usually sold to UK specialist traders and processors or direct to European wholesalers – only around 5% of which stays in the UK;

and live prawns, 90% or more of which is exported to European markets, mainly France and Spain, with a small proportion going to Italy.

- The size of whole prawn required for **tails** is anything above the current 20mm CL MLS, and includes both small whole prawns and damaged larger prawns.
- The market size requirement for **whole fresh or frozen langoustine** is anything above 32mm CL, but there is a substantial price premium on the larger grades.
- The size requirement for **live prawns** is also anything above 32mm, but some markets/traders will only take prawns above 40mm. Again there is a substantial premium for the larger grades, the largest of which may be worth double the price/kg of the smaller.

22. There is strong seasonality effect on prices of both whole fresh and live langoustine, with lowest prices early in the year, relatively steady prices through spring and summer, strengthening gradually in the autumn and peaking sharply just before Christmas.
23. Specific market opportunities may include the following:
    - There may be an opportunity for trawlers to meet some of the excess demand for live prawns in the autumn and at Christmas time when prices are particularly strong, although there is a danger that significant entry by trawlers into this market would lead to a reduction in price with negative consequences for creelers.
    - The market for whole fresh and frozen trawled prawns appears to have strengthened this year relative to that of live prawns, and this may reflect a longer term trend.
    - There are undoubtedly emerging market opportunities in east and SE Asia where prawns, size and novelty are all highly prized. It seems that the strength of the European market has served as a disincentive to market diversification in the past.
    - There are modest but probably increasing opportunities for local marketing initiatives in the more touristic areas. These are being taken up, and there are a variety of initiatives – including direct sales by skippers, and the emergence of more local seafood distribution companies.
24. Opportunities for marketing larger whole fresh, frozen or live prawns in the UK appear to be limited compared with export opportunities, and demand is already largely met through direct sales and specialist companies.

Short to medium term costs and returns associated with increased MMLS in the Skye and SW Ross case study area.

25. Based on existing cost profile of the various subsectors we developed a set of enterprise models typical of the case study area:
    - less than 10m creeler, less than 100 days at sea (das)
    - less than 10m creeler, more than 100 das
    - less than 10m trawler (excluding low activity)
    - more than 10m trawler (around12m)
    - more than 10 trawler (around 15m)
26. These models are parameter, cost and price driven, and any or all of these variables can be changed as required for particular scenarios. In particular, we have made the models productivity sensitive, in other words assumed that some costs are fixed irrespective of landings or value (e.g. depreciation, harbour dues) while others vary directly with days at sea (fuel, part of maintenance and gear costs). Some, such as commission vary with product value, and others (ice, boxes) with product quantity.
27. These enterprise cost models are linked to the product value spreadsheet to generate total costs and income under different assumptions of catch size profile and volume.

28. In all of these models the key performance indicator is taken to be return to labour (£/fisher/day at sea), calculated as total profit before labour compensation divided by (*days at sea x number of crew*)[1]; although it should be recognised that the skipper and crew spend substantial time ashore on maintenance, accounts etc. In other words this will be significantly higher than actual return to labour (£/fisher/day at work). We have not as yet incorporated return on capital, as this brings in many additional assumptions, but the model can be simply developed to generate this if required.
29. It is recognised that there are many assumptions, and that the baseline parameters may be somewhat inaccurate. Nonetheless we have sought to validate these with skippers, and from other published sources, and they represent a best estimate at the present time.
30. For illustrative purposes 2 possible future scenarios are applied:

    S1. Introduction of a scheme to reduce catch of smaller prawns (less than 25 or 30mm CL) for the whole fishery. This would only affect the trawl fleet since the market for live prawns (creelers) will not accept animals less than 32mm CL.

    S2. Introduction of MMLS of 40mm CL for the creel fleet

    It is assumed that the trawlers meet the demands of scenario 1 through a combination of gear modification and fishing strategy. The most optimistic sub-scenario assumes introduction of a relatively effective size-selective gear (e.g. incorporating a “french grid” and modified fishing practices, resulting in only a small loss of larger prawns and a significant loss of small prawns; the most likely sub-scenario assumes rather lesser performance, and the pessimistic sub-scenario assumes the kind of performance that has been demonstrated with some limited gear modification on the West Coast and Irish Sea.

    It is assumed that creelers meet the requirements of scenario 2 through fitting of escape hatches, optimal soak time, live discard, and possibly changes in fishing location and seasonality.

    For each scenario we make assumptions about parameters and costs at three levels – most likely, optimistic, and pessimistic. These models do not take account of possible medium or longer term benefits arising from increased yield. These are dealt with separately in the following section.

31. Return on labour for the base line fishing enterprises and scenarios is summarized in Table 1:

Table 1: Summary of returns on labour for baseline and scenarios

	Return on labour (£/das/crew) for 2 scenarios (4 sub-scenarios				
Fishing enterprise type	<10m creel (<100das)	<10m creel >100 das	<9.9m trawl	12m trawl	14.5m trawl/visitor
Baseline	28	252	91	162	257
S1 (opt.)			-9	43	148
S1 (ML)			-64	-26	84
S1 (pess.)			-121	-89	-14
S2	18	275			

[1] Equivalent to GVA per fisher (skipper and crew) per day at sea.

32. Several conclusions may be drawn:
    I. In relation to the baseline, if any significant depreciation and financing costs are assumed, many of the less active creelers are likely to be losing money. In reality many part timers may not be seeking to "turn a profit" in pure accounting terms, but rather to cover basic operating costs and make a modest contribution toward labour and/or depreciation costs[2]. Some indeed may be regarded as "hobby" fishermen seeking no more than recovery of basic operating costs.
    II. For the baseline as for the scenarios, varying days at sea has a major impact on returns. This is to be expected given the fixed nature of many of the costs. However, the assumptions regarding the breakdown between fixed and variable costs are uncertain, and it would be useful to refine these relationships through more in depth discussions with skippers at local level. A rough idea of the break-even number of days at sea would provide useful management information.
    III. The scenarios – even the optimistic sub-scenarios – all generate significant net losses relative to the baseline for the trawlers, although returns to labour remain positive in some cases albeit at a reduced level. This relates to:
        a. Reduced total landings, associated with reduced total catch per hour trawled (reduced CPUE);
        b. Reduced hours/day trawling as a result of changed practices to increase catch quality to allow access to higher value markets.

        These costs are unlikely to be compensated by the modest increases in the value of the catch in terms of £/kg landed.

    IV. For creelers results are highly sensitive to the assumptions about the impact of soak time on yield per haul and size profile of catch. If increased soak time results in a higher yield/haul, this may compensate for the loss of <40mm CL animals, but higher gear costs associated with increased soak time must also be accommodated. Overall we consider it unlikely that there would be significant changes in returns, but this will undoubtedly vary according to local fishing opportunities and marketing options.
33. It may be concluded that any attempt to introduce an increased MMLS for the trawl sector is unlikely to be supported unless substantial longer term benefits could be demonstrated (see next section).
34. Implications are less clear for the creel sector, and this conclusion is supported by the variation in practice at the present time, with some areas already implementing their own MMLS and associated practices, while others continue to market somewhat smaller animals through particular trading networks. Optimal strategy will depend on both the size profile of the prawns on local grounds, and access to markets with particular size preferences or limits.

Potential for stock and yield benefits

While the previous section dealt with immediate short (1-2 year) term impacts on returns to fishermen arising from shifts in gear or fishing practice designed to reduce landings of smaller prawns and (where possible) increase landings of larger prawns, the following explores the possible medium term (2yrs +) benefits arising from "letting the prawns grow" as might be expected to result from these changes in fishing practice. The following relates primarily to the North Minch *Nephrops* fishery, and to prawns primarily landed through trading networks from Skye and the NW.

[2] It is unlikely that anyone fishing part time will be paying finance costs for a vessel and gear, and will in all likelihood have previously "written off" the capital investment.

35. A yield-per-recruit approach coupled with decision theory is used to estimate optimal size of capture in the two fisheries, and the possible impact of the scenarios discussed above. This approach assumes that an animal should be retained if the expected benefit from retaining it exceeds the expected benefit from discarding it or avoiding its capture. The benefit from releasing or avoiding the capture of the animal is the sum over time of the probability of its capture at some future time multiplied by the value of the animal at the time of capture. The optimum size at which to capture a *Nephrops,* and by implication the MMLS, is that where the expected benefits arising from not retaining it are zero. Unlike the analysis in the previous section, this approach does not take into account possible variations in fishing costs.
36. For creels, where discard mortality is considered to be between zero and 10%, the optimum size for retaining females is around 25mm CL, and for males is around 34mm CL. This corresponds to retaining males as soon as they enter the 31-40 count per kilo size category. In other words, there is no strong case for an increase in MMLS above the current 34mm CL as determined by the market for live prawns.
37. For trawls, taking into account discard mortality, the model suggests that the optimum size for retention is slightly lower than the current MLS. If discard and escape mortality can be reduced, there is some benefit from avoiding capture of males of less than 25mm CL.
38. In all the scenarios, the management changes to selectivity result in a relative fall in the expected total value of the catch for trawl. This is because reduced overall catch rates offset any gains in utility per recruit (i.e. increased value associated with catching larger individuals).
39. In terms of longer term benefits to overall stock health, recruitment and fishery yield, the available data does not allow us to go beyond the stock assessments already conducted by Marine Scotland Science and ICES (2013). These suggest that the North Minch *Nephrops* fishery is being fished sustainably and at a level commensurate with maximum sustainable yield. The stock appears to be well above $B_{trigger}$, and overall fishing mortality appears to be below F_{msy}. However, there is substantial uncertainty relating to the total area of habitat (and therefore total stock estimates) and the nature and status of possible subsidiary stocks at local level.

Overall conclusions

40. Financial and yield per recruit modelling, suggests that introduction of a MMLS above the current 20mm CL MLS would have significant short and medium term negative effects on both costs and returns to trawler fishermen operating in the Skye and SW Ross case study area, and the North Minch more generally.
41. For the creel sub-sector an increase in MMLS to around 33mm CL would have a largely neutral effect on costs and returns in the short term, but would generate significant medium term benefits arising from the increased yield and value associated with larger animals. In practice market demand and the larger size-selective nature of creels means that most of the creel fleet is already implementing a MMLS of between 34 mm and 40mm CL.
42. Increasing MMLS across the board for a mixed creel/trawl fishery to 25mm or 30mm CL is likely to generate substantial gains to the creel fishery and losses to the trawl fishery.
43. The analysis highlights the fundamentally different interests of the creel and trawl sub-sectors in terms of both optimal stock management and product/marketing strategy, and suggests that a greater degree of physical separation, ideally corresponding with (at least partially) subsidiary stocks, would allow for more rational and optimal fisheries management in line with both stock management and marketing strategic needs.

44. Preliminary analysis of (limited) data relating to velvet crabs suggests that there is a case for increasing MMLS to as much as 77mm for at least part of the year.
45. The spreadsheet models of fishing enterprises as developed in this research, and the yield per recruit analysis could serve as the basis for structured and productive discussions with fishermen on the implications of alternative fishing strategies, management options and marketing strategies. They can be readily adapted to facilitate different forms of "what if" and sensitivity analysis.

Lessons learned

- The national datasets (UK MMO, the Scottish Government Marine Analytic Unit, the Seafish database on fleet economic performance etc.) are large, complex, subject to confidentiality issues, and only partially applicable to developing an understanding of fleet structure at local level. In retrospect the research team spent excessive time seeking to extract locally relevant information from these databases.
- Primary sources from fishermen, harbourmasters and traders in the case study areas were ultimately very valuable and informative. However the lack of any kind of formal agreement with industry on the research – and the (understandable) lack of support for/interest in research on MMLS for *Nephrops* on the part of the trawl fleet – greatly constrained early and efficient engagement with the industry. There needs to be more engagement with industry at the research design phase.
- Gaining a thorough understanding of the nature of a local fleet, the variations in fishing patterns and behaviour, the costs and financing structures of enterprises, the shifting market opportunities and strategies…..is demanding, especially with a fleet as diverse as the under 10m creel fleet. There is a real need for a far closer and longer term relationship between scientists and economists and fishermen, whether through inshore fisheries groups or through individual fishery representative organisations, so that researchers and fishermen can build a solid agreed foundation of basic analysis relating to both the fishery resource and the fleet itself.

2 INTRODUCTION

2.1 Background

Although fishing has lain at the heart of Scotland's economy and identity for centuries, it has seen substantial decline, at least in terms of employment and socio-economic importance, over the last 50 years.

Inshore fishing however remains significant: £90 million of fish and shellfish were landed by 1,500 inshore fishery vessels in 2013. These vessels comprise ¾ of the Scottish fleet and 18% of landed value.

It has also gained a higher political profile in recent years, with an annual conference and a parliamentary debate (29th April 2014[3]). As noted by Graeme Day MSP at that debate:

> *"Scotland's seafood already makes its way to 100 countries around the globe, with our salmon alone reaching 60 countries. In addition, two thirds of the world's langoustines are sourced in Scotland. The combined food and drink sector overseen by the Cabinet Secretary has come a long way. It is up from £3.7 billion in 2007 to £5.3 billion in 2012 and has already smashed the 2017 target of £5.1 billion. Now, we have a new target of £7.1 billion to reach three years from now".*

There have been significant initiatives in recent years to improve the management of inshore fisheries in Scotland. The Marine Scotland Inshore Fisheries Strategy 2012 included the development of a network of Inshore Fisheries Groups (IFGs) to cover the entire Scottish coastline. Fisheries management plans were developed for each IFG area identifying the constraints on sustainable fisheries development and management. A feature common to all these plans was the perceived lack of evidence upon which to base management measures.

An opportunity for funding to address this lack of evidence, and contribute to public sector policy and targets for the Scotland Food and Drink Industry Strategy, was identified by Seafood Scotland under the "Measures of Common Interest" (Axis 3) of the European Fisheries Fund (EFF). A proposal was therefore developed comprising 8 individual complementary Work Packages (WPs). These were seen as pilots to be undertaken over a relatively short timescale (14 months) and evaluated in the context of longer term support for effective future management of inshore fisheries and development of the industry.

The proposal was successful, and competitive tenders from individual contractors were sought for the various work packages. Hambrey Consulting successfully tendered with a proposal for work package 6: Integrating stock management considerations with market opportunities in the Scottish inshore fisheries sector – a pilot study. The objective of this study, as set down in the tender specification, was:

> *To undertake a pilot assessment of the potential economic and associated benefits of establishing minimum market landing size in excess of minimum legal landing size for key shellfish species; and to evaluate if such an intervention could be undertaken at a regional level.*

Subsequent exchanges with Seafood Scotland confirmed that the study would focus on two species: "Prawns" (*Nephrops norvegicus*), and velvet crab (*Necora puber*).

[3] http://www.theyworkforyou.com/sp/?id=2014-04-29.3.0

2.2 A Rationale for Increased Minimum Market Landing Size

Minimum landing size has been used widely as a simple management measure to safeguard stocks by ensuring that a reasonable proportion of animals grow and reproduce before they are captured. It has been used particularly in inshore shellfisheries (especially for lobster, crab and *Nephrops*) because implementation can be readily checked on board, at landing and within the value chain. A minimum landing size is already in place for both *Nephrops* and velvets[4].

Adherence to a minimum landing size may also be done in response to market demand. Many seafood markets pay a premium price for larger product size, and fishers may respond to this by seeking to increase the proportion of larger specimens in the catch – through changes in fishing patterns and techniques, modifications to gear, or simply by discarding smaller specimens. Whether any of this is done will depend on the costs of changes in fishing gear or practice, the loss of income from the catch foregone of smaller animals, and the increased returns associated with the larger animals. In practice both *Nephrops* creel fishers and velvet crab fishers already use combinations of these various strategies to increase the average size of their catch.

In the longer term the trade-offs between increased costs and catch foregone on the one hand, and increased income on the other, is further complicated by the possible impact of these strategies on the stock itself and the market price. It may be assumed that an increase in minimum landing size benefits the stock, and may lead to higher biomass and yield in future and/or a higher proportion of larger specimens caught. Equally, a higher production of larger specimens may reduce the overall differential in market price between small and large specimens.

2.3 Support for an increase in minimum landing size

Marine Scotland recently (2013) consulted widely on new controls in the *Nephrops* and crab and lobster fisheries and on increasing the MLS of West Coast *Nephrops*. Question 16 was *"Should the minimum size of Nephrops on the West Coast be increased to match those restrictions in the North Sea?"* . The outcome report of this consultation stated that a majority (in practice a small majority) were against increasing the minimum landing size of West Coast *Nephrops* and that "*we do not propose, at this time, to introduce any new measures in accordance with questions 1-16*". However some influential individuals in the industry are in favour of increased minimum landing size of *Nephrops*, at least to bring it in line with the North Sea. No questions were asked under the consultation regarding velvet crab minimum landing size.

It should be noted that this consultation did not address the desirability or otherwise of voluntary or locally based agreements for a minimum market landing size.

In our discussions with creel fishermen some strong views were expressed on the desirability of introducing an increase in minimum landing size. The creel sector already has a *de facto* minimum market size defined by market demand (traders; outlets) and this varies between 32 and 40mm depending on the particular trading/market outlets being accessed and in some cases seasonality. The view of the sub sector is simple: a larger prawn is more valuable; it makes no sense to remove it from the fishery at 20mm CL and turn it into low value scampi tails when it could be allowed to grow and sold whole or live for a much higher

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[4] *Nephrops*: 20mm carapace length, west coast; 25 mm east coast;
Velvets: 65 mm CW in all areas except Shetland (70 mm CW, under the Shetland Regulating Order)

price. Furthermore, catch per unit effort appears to be in decline, suggesting overfishing, and any measures to increase landing size are likely to benefit the stock.

Discussions with trawler skippers also generated a clear message: we have large efficient vessels that can catch a large volume of product that (despite its lower price) generates more income than would be possible through catching a smaller volume of larger higher value prawns. We are also supplying a low cost high quality product to the UK market. Since there is no scientific evidence of overfishing (as per ICES and MSS assessments), there is no case for a change in minimum landing size.

2.4 Purpose

Despite the widespread use of minimum landing size as a fisheries conservation measure, and the importance of size as a determinant of market value, there has been no comprehensive attempt to assess the likely medium to long term economic effect of changes in MLS or MMLS, taking account of both fishery stock and market impacts. The economic trade-offs are complex, with changes in MMLS having potential impacts on fishing and handling costs, stock composition, stock size, market supply and market price – and with different effects on total returns, and return per unit effort, for different kinds of fishing enterprise. An increase in MMLS could for example:

- reduce total catch in the short term, reducing *overall* returns[5];
- generate an immediate increase or decrease in return per unit effort, depending on the effect on catch rate of larger specimens, and the time required handling/discarding undersize specimens. Both of these may in turn be affected by changes in gear arising from an increased MLS rule;
- result in an increase in the fishable stock of larger specimens in the longer term, and an increase in the proportion of larger specimens in the total catch. This may or may not compensate the loss of returns from smaller specimens, depending on relative price and abundance, as well as fishing and handling costs associated with different sized organisms;
- result in increased reproduction and fecundity of the stock, resulting in a larger and/or denser stock, with the potential to increase total returns from the fisheries and/or increase catch (and returns) per unit effort. However, there is some evidence to suggest that size in the *Nephrops* fishery, and possibly some other shellfisheries, is density dependent, further complicating potential impact;
- reduce the product range and reduce opportunities for market segmentation. As the proportion of larger specimens increases, the price may fall, and the differential between larger and smaller specimens may decrease, undermining the original rationale for increased MLS;
- enhance product reputation leading to increased demand, and price, overall;
- (if undertaken at a local or regional scale) result in differential economic fishing opportunities in different areas in both short and long term, with knock-on effects on fishing effort and stock management.

These issues have never been comprehensively addressed for inshore fisheries in Scotland; indeed, market price is rarely factored into stock management mechanisms anywhere in the world. This research therefore has the potential to break new ground in fisheries economics and management.

The study purpose (as specified in tender SFS006SIF) is:

[5] Only where the marginal cost of catching and handling smaller animals exceeded the return generated, might the overall return be maintained. This is unlikely in a rationally exploited fishery.

To undertake a pilot project to assess the potential economic and associated benefits of establishing minimum market landing size in excess of minimum legal landing size for Nephrops and velvet crab; and to evaluate if such intervention could be undertaken at a regional level.

The project had 4 operational objectives:

1. Within pilot areas and for identified species, determine the size distribution of individuals landed (above MLS) from stocks on a seasonal basis
2. Establish costs and returns associated with different sized specimens
3. Establish consequences of introducing MMLS above the current MLS through pilot economic assessments.
4. Evaluate the potential for increased MMLS as a tool for improved returns and fishery sustainability

3 METHODOLOGY

The overall approach to this study has been the synthesis and integration of diverse information and analysis relating to *Nephrops* biology and stock modelling, the social and economic importance of inshore fisheries in case study areas, the market for *Nephrops* products, and the micro-economics of inshore fishing enterprise. It also necessarily explores practical constraints on management and management policy.

3.1 Engagement with industry

It had originally been the intention to establish a steering group comprising local industry (fishing and trading) representatives. In practice we found little support for this at local level, and it was agreed with programme management and industry representatives that more informal relationships should be built up with the local fishing and trading community. This was successful to a point, but engagement was more limited than we would have liked, primarily because there was widespread scepticism amongst the fishing community about the feasibility of introducing any change in minimum landing size, voluntary or otherwise, given that the markets and interests of creelers and trawlers were so fundamentally different.

3.2 Logic

The logic of the methodology is as follows:

1. Make industry contacts in cases study areas in both creel and trawl sub-sectors;
2. Develop socio-economic profile of case study area, and an understanding of the structure and economic contribution of the case study area fleet;
3. Review and synthesise existing data on size profile of the catch;
4. Seek an improved understanding of the factors that determine catch size profile, and in particular fishing technology and practice, from literature and industry sources;
5. Develop an understanding of any costs that may be associated with individual (vessel) actions or strategies to increase the size profile of the catch;
6. Develop an understanding of the market and market trends, and the prices associated with different sizes of product;
7. Develop economic models of representative fishing enterprises, including relationships between fishing costs and any changes required to increase MMLS, and between returns and size profile of catch;
8. Using plausible scenarios for representative enterprises, and for the fleet as a whole, use the models to explore likely economic consequences of any changes in MMLS;
9. Using stock assessment techniques, explore the consequences in terms of possible future increases in yield from the fishery;
10. Discuss the overall costs and benefits, and the feasibility of introducing a MMLS at a regional level.

3.3 Choice of case study areas

It had been hoped that case study areas would be "self-selecting" - in other words that particular IFGs would request that the work be done in their area, because of a particular local interest. In practice, although "expressions of interest" in promoting the project locally were solicited (through the research programme management and IFG network), there was no clear outcome to this process. However, discussions with individual IFG chairs and secretaries resulted in some positive responses: in particular from the Northwest IFG and the Western Isles IFG. The TOR also required a case study on the East Coast, and while there was no specific request from local interests, an obvious focus for such a study - to complement those of the West Coast - appeared to be the Inner Moray Firth *Nephrops* trawl fishery, prosecuted primarily by vessels from Burghead.

The study began with the intention of undertaking these three case studies, and significant groundwork was done in all three areas. However, the scope and complexity of the work and the time required to engage effectively with the local fishing and trading community, and fully understand the nature of the fleet and local fishery resources, led to a decision to concentrate on one case study (Skye and SW Ross) but to refer to two other areas (The S Uist Velvet crab fishery, and the Burghead prawn fishery) as a part of broader discussions of the issues.

However, we have been provided with significant information on the other case study areas and undertaken some preliminary analysis, and it would be relatively simple and highly cost effective to extend the work to cover these case studies under any future research programme.

3.4 Data Sources

We have drawn on a wide array of literature and statistics relating to all dimensions of this study, as well as those relating to other similar situations elsewhere or related issues. These sources are referred to as both footnotes where appropriate as well as in the bibliography.

We have also talked to many people: scientists, fishermen, seafood traders, restaurateurs, distributors, harbourmasters and so on. In most cases these were informal discussions or semi-structured interviews, allowing us to understand the full scope of the issues or draw on particular knowledge and experience. Several IFG and SIF project meetings were also attended that provided important background insights. A full list of consultees is presented as Annex 1.

More formal data sources were as follows:

- Socio-economic data relating to the case study areas was derived mainly from national statistics (ONS), and in particular the Scottish Neighbourhood Statistics and the 2011 Census data, along with sources related to local economic development planning.
- Data relating to fleet structure in case study areas was derived from the UK fleet register, the UK MMO and Scottish Sea Fisheries Statistics, and custom data developed for the SIF programme by the Marine Scotland Marine Analytical Unit. This was validated, refined and further developed through discussions with local skippers and harbourmasters.
- Information regarding the economic performance of the fleet was derived from both local sources and from the Seafish economic performance database. This can be accessed online in aggregated format [6] but was also interrogated directly at a more detailed level at the Seafish offices in Edinburgh.
- Market information has been sourced from national production and trade statistics, HMRC, directly from seafood traders, and from previous reviews. Several commercial seafood companies provided a wealth of information on product, volume and price trends over several years which has been invaluable for this study. Unfortunately we were not able to access significant parts of the Scottish seafood buyers and sellers database for reasons of protocol and confidentiality.

[6] http://www.Seafish.org/research-economics/industry-economics/Seafish-fleet-economic-performance-data

- Stock assessment data was provided by Marine Scotland Science, and many of their publications served as crucial underpinning to the analysis. The various research studies commissioned in relation to MSC certification of the Torridon Creel Fishery and Stornoway North Minch Trawl fishery were also especially valuable. The thesis of Adey (2007) was of particular value for cross checking many assumptions.

3.5 Economic modelling

Simple vessel/enterprise financial models were developed in spreadsheet format allowing for maximum accessibility and flexibility. These are driven by key operating parameters and cost/price information so that possible impacts of changes in gear or fishing practices can be explored. These parameters/prices are related to the questions posed by this research, and include in particular:

1. Days at sea
2. Trawl tow duration
3. Trawls per day
4. Creel hauls/day
5. Soak time
6. Catch per unit effort (kg/100 creels hauled; kg/hr trawled)
7. Size profile of catch
8. Value profile of catch

One or more relationships have been defined between these parameters or arrays and the various operating cost and income categories.

We have then defined several plausible scenarios, associated with different approaches to implementing a MMLS, that will determine these parameters, and in some cases the relationships between these parameters and costs, and then explored the likely financial consequences of these scenarios. Alternative scenarios or the effect of different specific parameter values or prices can also be readily explored.

This has been undertaken for 5 representative enterprise types (2 creel; 3 trawl). Based on our understanding of the local fleet structure, this can be readily scaled up (raised) to define economic impact on the fleet based (mainly) in the case study area.

3.6 Stock modelling

For the stock modelling, a utility-per-recruit and decision theoretic approach has been used, based on background data and parameters provided by Marine Scotland Science and commercial data provided by a Scottish processor/trader. The utility-per-recruit is a simple extension of the standard yield-per-recruit method used to advise on minimum size and reference points for stock assessment. Although a little more complex, using decision theory is a better approach, as it deals with uncertainties explicitly and is more flexible, so that a wide range of factors which might be considered important can be accounted for.

The decision theory approach suggests that an animal should be retained if the expected benefit from retaining it exceeds the expected benefit from discarding it or avoiding its capture. The benefit from releasing or avoiding the capture of the animal is the sum over time of the probability of its capture multiplied by the value of the animal at that time of capture.

More details of the methodology can be found in Annex 4.

4 PREVIOUS STUDIES

This section summarises some of the main studies that have been undertaken relating to minimum landing/market size for *Nephrops* and velvet crab. In practice a much broader literature is relevant to the questions posed in this research, but this is referred to explicitly in relation to parameter and model development in subsequent sections.

In practice there has been very little analysis of the economic impact of shifting landing size in favour of improved stock status and market opportunity.

Fourteen years ago Ulmestrand and Eggert (2000)[7] developed a bio-economic model of the Swedish *Nephrops* fishery exploring impact of different gears with different selectivities on long term economic benefit. Although the study provides interesting comparisons of the costs and benefits associated with different types of fishing operation, it offers rather little insight into the wider costs and benefits that might be associated with different size profile of landings.

ICES (2007) undertook a meta-analysis of the effects of gear changes on retention and selectivity, and took this one step further to explore possible effects of gear changes on stock biomass and landings. They present baseline, and impact on landings and stock biomass for changed gear options (increased mesh size; use of square mesh; use or not of lifting bag) for several case study areas including the Firth of Forth. The stock predictions are based on length cohort analysis. They find, for example that where a lifting bag is used an increase in mesh size from 80 to 90 generates short term landings losses of 0.5% (male) and 4.7% (female) and longer term gains of 2.6% for males and continuing losses of 1.3% for females. There are short and long term stock gains for males of 3.4% and 5.2% respectively and for females 1.7% and 5.1%. Much more significant gains in both landings and stock are generated by not using a lifting bag, by using square mesh panels or by increasing mesh size to 120mm. However, short term losses of more than 40% may be experienced. They conclude that “improving selectivity has a greater negative effect on landings of females than of males, and smaller positive effect on female biomass. In all the gear options chosen, a positive effect on biomass is seen – as expected – but it is only for males in the long term that there may also be a positive effect on landings. In most cases, the increase in biomass does not counteract the loss of marketable *Nephrops* due to the selectivity increase”. They emphasised that the examples given were for illustrative purposes and that the predictions should be “treated with caution”. This is in large part because there is a great deal of variation and uncertainty in the data.

More recently, Macher and Boncoeur (2010) developed a relatively sophisticated bio-economic model to explore optimal gear selectivity and effort cost in the Bay of Biscay *Nephrops* fishery. They concluded the fishery was operating well below its economic potential. This related largely to the fact that benefits of increasing selectivity do not immediately accrue to the individual fisher; the chances that the same person will catch exactly the same creature again, but bigger, are vanishingly small. This is the classic dilemma of open access fisheries management that tends to undermine any form of voluntary or “self”-regulation.

Raveau et al (2012) also developed a bio-economic model of the French mixed *Nephrops*/Hake trawl fishery. They assessed the short- and long-term bio-economic impacts of four experimental selective devices aimed at reducing *N. norvegicus* and *M. merluccius* discards over a 20-year simulation period. Costs and benefits were analyzed with the objective of finding the best compromise between a reduction in discards of undersized animals and a loss of valuable catches arising from use of more selective gear. Their selectivity scenarios suggested positive impacts on stocks but different economic impacts between fleets. The most cost effective gear appeared to be a combination of a square mesh cylinder with a grid and square mesh panels, although actual trial results were highly variable.

Some work has been done on the financial implications of a discard ban, at least for *Nephrops* which is relevant to consideration of an increase in the MMLS, certainly in terms of gear adjustment. Cappell and Macfadyen (2013) reported to the UK Discard Action Group (convened by Seafish) on the potential implication of proposed Common fisheries Policy (CFP) landing obligation i.e. a discards ban. They used the *Nephrops* trawl fleet in the North Sea and the Irish Sea as case studies and considered "choke" species and quota implications.

Less work has been done on velvet crab fisheries than on *Nephrops,* but a paper by Fahy et al. (2008) discusses their sustainability. Marine Scotland Science (Shelmerdine and White 2011) has done some work on the economic benefits that might be associated with escape gaps for velvet crabs, but despite its title this does not address economic dimensions and is covered below in the section on gear impacts.

Despite the lack of economic analysis there is a substantial literature on gear, especially *Nephrops* trawls and this is reviewed in detail in section 8.

Previous studies: main findings

- Very little work has been undertaken that explores the possible impact of increased MMLS on the economics of fishery production, taking into account both stock and market effects/opportunities.
- The work of the 2007 ICES working group offers some insights into these questions but is based on meta-analysis of highly variable data, and was undertaken largely for illustrative purposes

5 NEPHROPS BIOLOGY AND MANAGEMENT

Ultimately the productivity and sustainability of a fishery, and the impact of any measures such as changes in landing size will depend on biology. This section offers a brief introduction/background. More detailed review in relation to specific issues is presented in the sections on parameters and modelling.

5.1 Distribution, habitat

Nephrops are widely distributed throughout the north-east Atlantic from Iceland in the north to Morocco in the south, including the Mediterranean in water depths ranging from 20 to 800m. There are substantial populations in the North Sea and waters to the west of Scotland, including the sea lochs, Minches and the shelf edge west of the Hebrides.

At a more local level, *Nephrops* distribution is limited by the nature and extent of suitable substrate in which they construct burrows. This is primarily fine or silty mud. The nature of this substrate may impact size profile (see section 8).

Burrows may be up to 10 cm in diameter, over a metre long and penetrate the sediment to a depth of 20-30 cm (Rice & Chapman, 1971). Burrows of juveniles may be attached to those of adults.

5.2 Abundance, density and size

Several studies along with on-going monitoring show there to be significant geographical and temporal variability in the abundance and size of *Nephrops* taken by trawls. Density may vary between 0.12 and 2 ind/m^2 (Chapman & Rice 1971; Mclay et al 2008) and there may be some density dependent effects, with larger specimens often found at lower density (Adey 2007). In the North Minch the absolute density observed in recent UWTV surveys is ~0.6 burrows/m^2 (ICES 2013). Substantial variation occurs in both fished and non-fished areas, suggesting other factors may be responsible, such as substrate (food, burrowing); weather/climate; and hydrodynamics/settlement. This variation has significant implications for the likely effects of, or response to, any changes in landing size.

5.3 Food

Nephrops are opportunistic predators, primarily feeding on crustaceans, molluscs and to a lesser extent polychaete worms and echinoderms (Parslow-Williams et al., 2002). During periods of food scarcity, females spend a prolonged period in their burrows and suspension feeding is thought to occur (Loo et al., 1993).

5.4 Predators

In Scotland cod is a major predator on *Nephrops.* A study by Thomas (1965a) revealed that 80% of cod examined had *Nephrops* amongst their stomach contents. *Nephrops* remains were also found in 52% of the thornback ray *Raja clavata* sampled. In the Clyde, *Nephrops* was found in 51% of Lesser spotted dogfish (*Scyliorhinus canicula)* sampled (Gordon & De Silva, 1980). It is possible that increases in abundance of *Nephrops* in recent decades may be partly related to the decline of demersal fish stocks. Equally the increase in *Nephrops* may now be benefitting previously non-targeted species – hence the rise in abundance of skate and dogfish in the Minch as currently reported by some fishermen.

5.5 Maturation and reproduction

Female *Nephrops* mature at two to three years of age and reproduce each year thereafter; males mature at age three (Mclay et al 2008). Size at maturity for females has been estimated at between 20mm CL (10%) and 40mm CL (90%) with 50% maturation at around 28mm CL (Ulmestrand & Eggert 2000) although this is likely to vary significantly between different areas/habitats. Some previous studies in the Irish Sea suggest age at onset of maturity of 3 to 3.5 years in females and 4 to 4.5 in males. Tuck et al., (2000) suggested that size at sexual maturity ranges from 21 - 34 mm in females and 29 - 46 mm in males, and is positively correlated with asymptotic length and negatively correlated with adult density. Lifespan is thought to be 6-10 years.

The literature suggests that the timing of reproduction may be quite varied, but with mating/fertilization in summer/autumn and spawning shortly thereafter; and the eggs then carried on the abdomen of the (berried) female for 6-9 months until they hatch in April-June. There may be between 1,000 and 5,000 eggs, but up to 50% may be lost during the incubation period. Females tend to remain in their burrow in the early part of the year while the eggs are developing.

The larvae go through 4 stages (3 of which are free-swimming) over a 6-8 week period (Mclay et al 2008) prior to becoming a juvenile *Nephrops* (CL 2-3mm) and settling. Hillis (1972) reported that larvae of *Nephrops norvegicus* in the Irish Sea were dispersed by the local hydrographical conditions but they generally remain in the hatching areas of adults without being transported long distances. The main concentration of larvae in the Irish Sea were found in and near deep water. Once settled, they are thought to share the burrows of adults for the first months of their lives before constructing their own.

5.6 Growth and size

Growth is not continuous, rather it takes place at moulting which occurs at least once a year. An animal may grow by 7.1% at the time of moult (Thomas 1965b). Age is difficult to determine, so it is usual to use size as a proxy.

Nephrops grows to a maximum total length of around 25 cm (including the tail, carapace and clawed legs), although more usually between 18-20 cm. The maximum recorded carapace length (CL – the standard measure) has been recorded as 80 mm, although in recent years specimens larger than 60 mm CL are rare (Johnson and Johnson 2013).

Nephrops in different areas grow at different rates and mature at different sizes. This variation appears to be related to both the density of animals (with lower growth at higher density (Tucker et al 1997a), and sediment type. There is also evidence that growth is correlated with in-faunal biomass, and possibly also social behaviour.

On the softest mud, *Nephrops* density tends to be low, but the animals grow relatively fast, and reach a larger maximum size ('clonkers'). On sandier mud, density is usually higher, but the animals grow more slowly, and remain small ('beetles'). On course sediments low density and high growth is found, indicating that these relationships are complex and non-linear.

Estimates for biological parameters for the North Minch Functional Unit, based on a wide range of sources are given by ICES (2013) (Table 2).

Table 2: Biological parameters for Nephrops in the North Minch Functional Unit (after ICES 2013)

Biological parameters – FU 11

PARAMETER	VALUE
Discard Survival (trawl)	25%
Discard Survival (creel)	100%
MALES	
Growth – K	0.16
Growth - L(inf)	70 mm
Natural mortality - M	0.3
Length/weight - a	0.00028
Length/weight - b	3.24
Size at maturity	27 mm
FEMALES	
Immature Growth	
Growth – K	0.16
Growth - L(inf)	70 mm
Natural mortality - M	0.3
Size-at-maturity	22 mm
Mature Growth	
Growth – K	0.06
Growth - L(inf)	60 mm
Natural mortality - M	0.2
Length/weight - a	0.00074
Length/weight - b	2.91

5.7 Stock structure and recruitment

Considerable variation in *Nephrops* growth rate, mean size, size at maturity, fecundity and burrow density, have been found over comparatively small distances, and may be associated with local hydrographic and sediment conditions (Chapman and Bailey, 1987; Tully and Hillis, 1995; Tuck et al. 1997; Sarda, 1998; Tuck et al., 2000). This suggests that some *Nephrops* 'stocks' consist of a number of sub-units or 'stocklets' (Chapman and Howard, 1988). In the North Sea differences in growth have been found between stocks, while on the west coast, differences between areas within the same stock have been found.

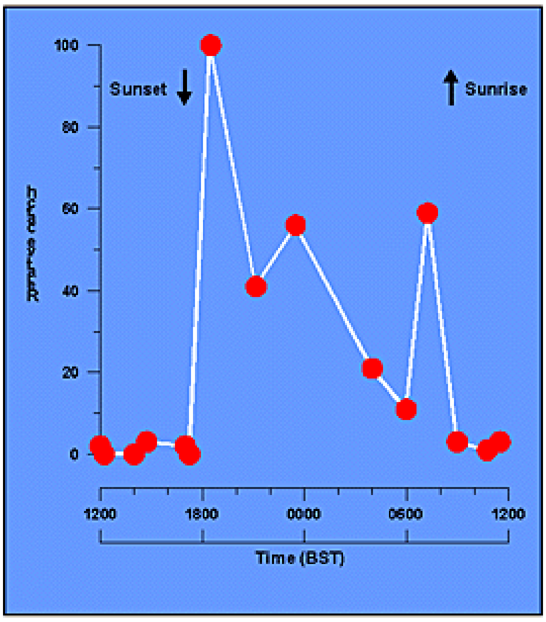

Figure 1: Diurnal activity pattern of Nephrops

It has proved very difficult to come up with a recruitment index.

5.7.1 Behaviour

The lifestyle of *Nephrops* affords it a certain amount of protection from fishing pressure. *Nephrops* spend most of their time in burrows, only coming out to feed or look for a mate. Burrows may be up to 10 cm in diameter, over a metre long and penetrate the sediment to a depth of 20-30 cm (Rice & Chapman, 1971).

Tagging experiments have shown that *Nephrops* do not migrate large distances, indeed they are likely to stay within 10m of their burrow (Marine Institute, 2001; McLay et al 2008). They are highly territorial, aggressively defending their burrows (Marine Institute, 2001). Berried females spend more time in burrows than non-berried females and males, so they are naturally protected from trawlers, and males dominate (as much as 80%) trawl catches for much of the year[8] (Eggert and Ulmstedt 2000). The catch in creels is more evenly balanced. This suggests that while growth overfishing is more likely to be associated with the trawl fishery, recruitment overfishing could occur in the creel fishery. Juveniles remain within their burrows for most of the time until they become sexually mature (Chapman, 1980).

Clearly, emergence patterns will affect catch rates. The timing of burrow emergence appears to be confined to a narrow range of 'optimum' light intensity on the sea bed, and this optimum is related to both depth and diurnal rhythms. *Nephrops* tend to be nocturnal in shallow water, active during the day-time in deep water, and active at dawn and dusk (crepuscular) at intermediate depths (Chapman & Rice, 1971). However, the attraction of bait in a creel fishery may override these typical rhythms (Watson & Bryson, 2003).

Nephrops move around by crawling or occasionally "jumping" using a flip of the tail. This affects their vulnerability to capture – they rarely rise far above the sediment – so they may be taken with trawls with relatively shallow headlines, and this may allow more active swimming demersal fish to escape and ensure a relatively "clean" catch.

5.8 Management

ICES (2013) has proposed the following management reference points for the North Minch *Nephrops* fishery:

Table 3: management reference points for the North Minch Nephrops fishery (ICES 2013)

Harvest ratio reference points

	MALE	FEMALE	COMBINED
F_{MAX}	11.1	23.0	13.2
$F_{0.1}$	6.9	12.8	7.7
$F_{35\%SpR}$	8.2	19.6	10.9

	TYPE	VALUE	TECHNICAL BASIS
MSY	MSY $B_{trigger}$	538 million individuals	Bias-adjusted lowest observed UWTV survey estimate of abundance (corrected for the new VMS area estimate)
Approach	F_{MSY}	10.9% harvest rate	Equivalent to $F_{35\%SpR}$ combined sex. F_{MSY} proxy based on length based Y/R.

According to latest (2012) ICES advice, west coast stocks appear to be stable and fished around or below F_{msy}. UWTV surveys suggest that abundance is well above $B_{trigger}$.

[8] http://www.scotland.gov.uk/Topics/marine/marine-environment/species/fish/shellfish/Nephrops

***Nephrops* biology and management: main findings**

- Size at maturity is around 21 - 34 mm CL in females and 29 - 46 mm CL in males.
- Juveniles tend to stay in burrows and are rarely caught before maturity.
- Females are smaller than males and less likely to be caught, especially in trawls.
- There is substantial variation in the size profile of *Nephrops* taken from different habitats/substrate types.
- The burrowing habit, and behaviour of females, offers some protection against over-fishing.
- *Nephrops* do not migrate significant distances and are highly territorial.
- It is likely that there are several, possibly many subsidiary stocks, especially on the West Coast.
- According to most recent UWTV abundance survey and fishing mortality estimates, the North Minch stock overall is being fished sustainably, although there are uncertainties regarding possible subsidiary stocks.

6 CASE STUDY AREA: SKYE AND SW ROSS

The case study area encompasses Skye, Lochalsh and the southwest part of Ross and Cromarty corresponding to SNS intermediate geography areas S02000724, S02000725, S02000745, S02000746, S02000751.

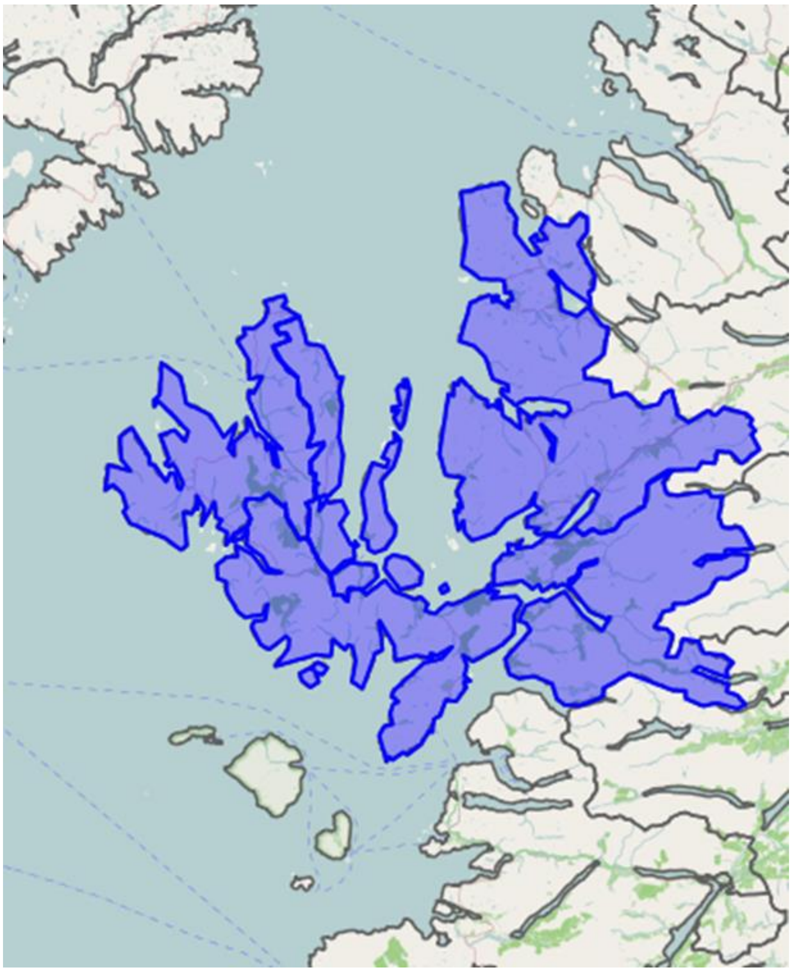

Figure 2: Case Study Area Skye and SW Ross

This area corresponds closely to the Portree Fisheries District and is relatively coherent in terms of a fishing community. This allows for comparison and aggregation of data from a range of sources.

The main locations of fishing activity in the area are Portree, Broadford, Kyle, Sleat, Strathaird, Portnalong, Bracadale, Carbost, Uig, Dunvegan, Snizort, Torridon, Sheildaig, Applecross. This excludes both Gairloch and Mallaig which are significant fishing locations in their own right, but belong to different fisheries Districts. Although we have defined the case area as above, it is not possible discuss the fishery without reference to these and other adjacent areas and ports, and this has been done as appropriate throughout the report.

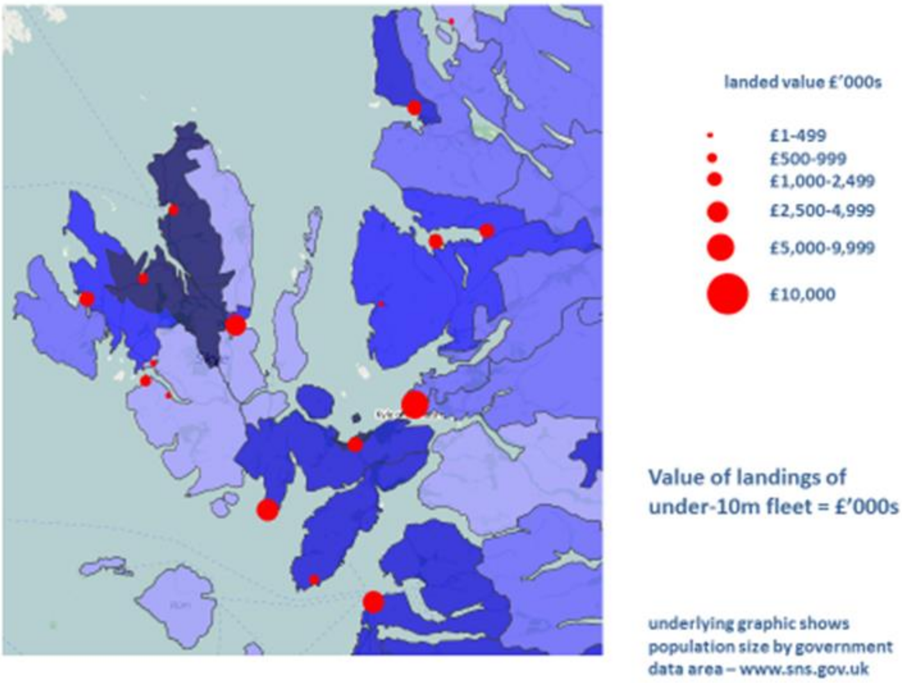

Figure 3: Value of landings (less than 10m) to different ports or creeks in Portree District and adjacent ports

6.1 Socio-economic characteristics

6.1.1 Economic performance

The economy of the case study area is relatively buoyant and GVA/head (equivalent to profit + wages) has increased steadily in recent years.

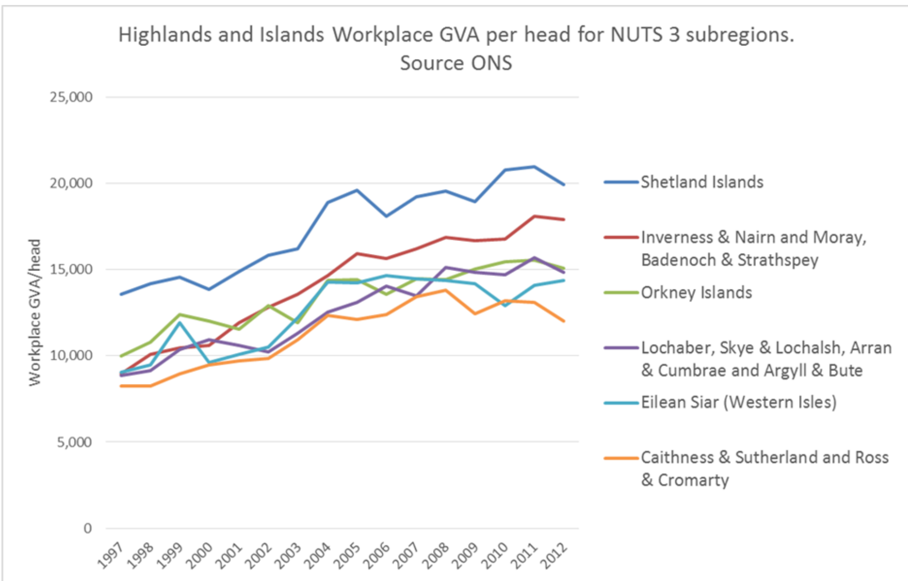

Figure 4: Economic performance of case area relative to other regions of Highlands and Islands

6.1.2 Economic sectors and the role of primary industries

The main growth has been in public administration and health services as well as real estate activities. Other sectors have been less successful and there appears to have been some decline in the agriculture, forestry and fishing sub-sector.

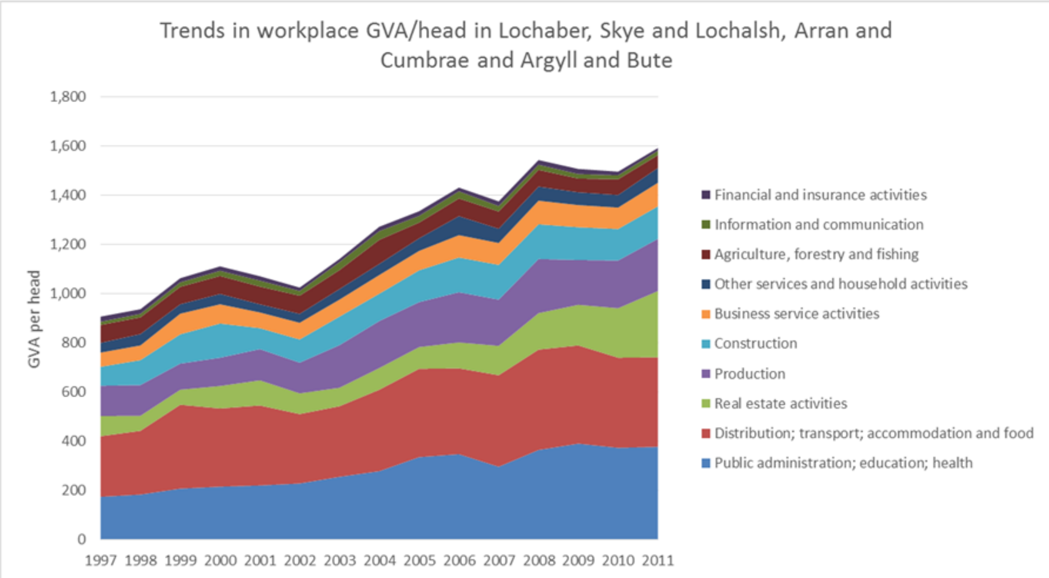

Figure 5: Economic performance by economic sector

However, when the economy is examined in terms of private sector business we find a very different structure and relatively more steady trends. Primary industries (of which fishing is a significant part in the case area) are the most important in terms of VAT registrations (i.e. significant businesses) and showed a slow but steady increase until 2013. This suggests that primary industries support a relatively large number of small businesses, and by implication, significant levels of employment and contribution to the local economy.

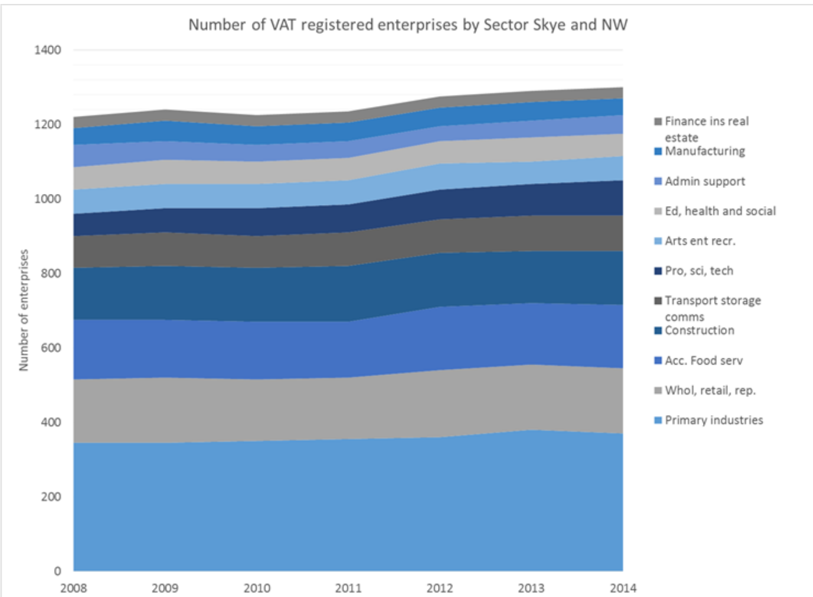

Figure 6: Contribution of primary industries to business VAT registrations

6.1.3 Population profile and skills

Total population of the area is around 16,000, and there has been steady increase over the last decade. The population of Skye in particular increased by 8.4% between 2001 and 2011. However, the working age population has remained relatively stable, and the proportion of children has declined slightly. The main growth has been of people of pensionable age.

The Highland as a whole boasts a significantly higher percentage of skilled trade relative to the national averages, though somewhat lower professional. Other categories broadly similar. Qualification levels are slightly higher than the national averages.

6.1.4 Social indicators and employment structure

School leavers from the area do relatively well with around 90% achieving positive outcome in follow up years. Median household income stands at £458/week, a little below the Scottish average of £468, and 16% of households are classed as "materially deprived", compared with 17% at Scottish level.

The level of self-employment in the main population centres of Portree, Broadford, and Kyle is significantly higher than national level (around 13% compared with 7.7% at national level), while unemployment amongst 16-74 year olds is close to the Scottish level of 6% . The Skye, Lochaber and Wester Ross area as a whole has a relatively high proportion of people working from home (over 1 in 5).

6.2 The historic role of fishing

Some insights into the historic nature of fishing on the West Coast and Hebrides are provided by Thomson (2004). He charts the development of the industry and its role in society from its beginnings stimulated primarily by famine and the clearances in the 19th Century, through the times of relative diversity and abundance of species, to the beginnings of depletion in the mid to late 20th century, and the tendency toward capital intensification and concentration of ownership in the late 20th century, associated with the CFP, and increasing levels of trade in licenses and quota.

The industry is now a very different animal, highly dependent on *Nephrops* (a mere bycatch species in earlier fisheries). Some of the previous trends (decline and capital concentration) have been reversed because of the opportunities for creeling for high value live product using relatively small (less than 10m) vessels with a crew of 1 or 2. Economies of scale are less apparent in this sub-sector, and the result has been to maintain a substantial less than 10m fleet employing relatively large numbers of people. This is developed further in the next section.

7 FLEET PROFILE AND PRODUCTION ECONOMICS

This section explores and summarises existing data on fleet structure and economic performance of the inshore fleet with more detail in the main case study area. It draws primarily on the UK MMO fleet register, UK and Marine Scotland fishery statistics, the Seafish economic performance database, interviews with skippers, harbourmasters and others in cases study areas, and data made available by commercial trading enterprises. Wherever possible we have sought to "triangulate" data from different sources, but there are inevitably discrepancies and divergences in the data related to allocation and boundary issues, seasonality, longer term changes and other issues. Most of these are minor, but where there is significant uncertainty or discrepancy we have flagged this up.

While the main focus has been on vessels based within the case study areas, we have also sought to profile

a) Vessels from adjacent ports that fish in the area and may occasionally land in the area;
b) Vessels from further afield that take a significant proportion of the catch, and may land locally or further afield

Throughout the following text, and especially in relation to fleet size and structure we refer to most numbers as approximate or rough. This is because of the significant variations from season to season and year to year, the wide range of uncertainties related to the level of current activity, boundary/allocation issues, inaccuracies in data sources, and discrepancies between sources etc.

7.1 Northwest and Western Isles fleet structure

The shellfish fleet based in the Northwest and Western Isles as a whole is dominated by vessels in the 6-10m category (Figure 7) which are mostly creelers, but with significant numbers of 12m and over (mainly trawlers). This structure seems to be fairly typical of most areas in the West, though in general somewhat larger (typically 12-15m boats) operate out of Stornoway, Gairloch, Mallaig and Oban, and rather smaller vessels are based in Skye and SW Ross.

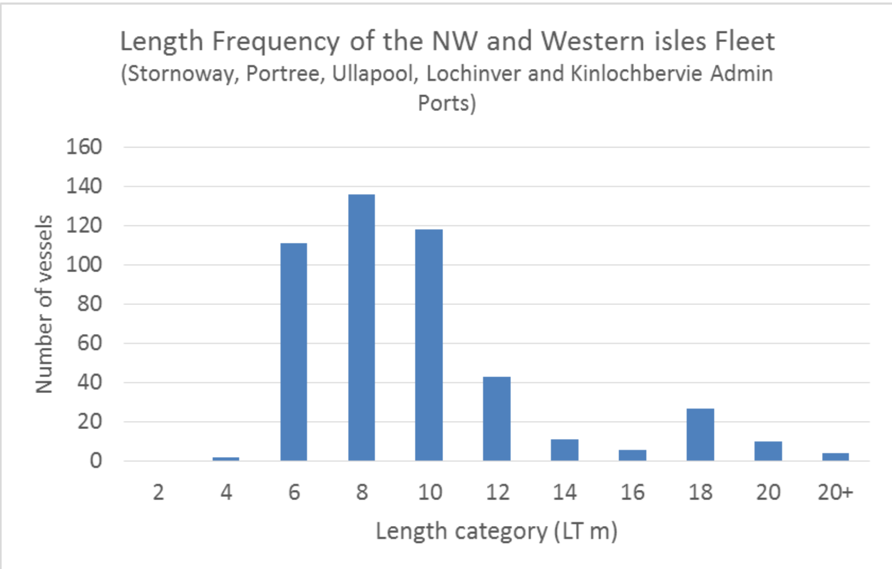

Figure 7: Size profile of vessels operating in NW Scotland and the Western Isles

This data corresponds closely with the Seafish less than 10m pots and traps fleet segment as a whole whose average size is around 8m. It also corresponds well with the group of vessels that we have identified as operating in the case area (see below).

Although creel vessels are usually categorized as less than 10m and more than 10m this category is not particularly useful: the vast majority of creel vessels are in the 7-11m size category.

7.2 Skye and SW Ross Case Area

Between 120 and 130 vessels are based within the case study area of which close to 100 are less than 10m. Roughly 24 of these are trawlers, most of which are more than 10m, though several larger vessels are based at Gairloch and Uig. The rest are mainly under 10m creelers, and there are two more than 10m scallopers.

The MMO landings data shows that around 11 less than 10m trawlers land to the case study area, and we are aware of 10 such vessels based locally. A further 14 over 10m trawlers operate in the area of which 4 are visiting vessels. 3 of the trawlers (2 less than 10m and 1 more than 10m) are classed as low activity in the Seafish database.

Table 4, derived from discussions with local traders and fishermen, summarizes the characteristics of the local fleet and those other vessels that regularly land in the area.

This corresponds reasonably with the Seafish database which suggests a local fleet of around 63 active under 10m creelers (around 80% of the vessels landing to ports in the area).

7.2.1 Species caught

The vast majority of (trawl and creel) vessels target *Nephrops*. However, several of the trawlers operating in the area also creel at times and may take crabs, lobster, and whelk. One trawl vessel alternates between prawns and scallops. Another regularly lands a small bycatch of whitefish.

Amongst the creelers, a few specialize in velvets, and several take them seasonally; at least 7 take brown crab; and at least 4 also take lobsters.

2 dive boats operate in the area based out of Kyle and Kyleakin taking scallops and occasionally shrimp

Table 4: Structure of the Skye and SW Ross Case Study Fleet (mainly local sources)

Sub-segment	No. of vessels	Power KW	Crew/vessel
less than 10m trawl specialist prawn	6	80-100[9]	1-2
less than 10m mixed	4	90-200	Mainly 2
more than 10m trawl specialist prawn	8	94-350	Mainly 2; one larger vessel (350kW) with 4-5
more than 10m trawl mixed	2	126-135	2-3
Visiting trawlers	4	90-256	1-5
Total trawl	***24***		
less than 10m creelers Nephrops	32	26-285	1-2
less than 10m creelers mixed	17	22-224	1-2; mostly 2
less than 10m creelers – low activity/ltd info	30-40?	6-119	
more than 10m creelers Nephrops	3	75-364	2-4
more than 10m creelers mixed	4	56-134	1-3
more than 10m creelers low activity/unknown	2	80-126	
Visiting more than 10m creelers	2	23-53	1-3
Total creel	***100***		
Scallop diving/shrimps etc	2	37-80	
Totals	***126***		

[9] One outlier at 42KW

7.2.2 Activity

The Seafish database provides specific data on days at sea. This suggests that of the ca 20 trawlers based in the case area, 3 were relatively inactive in 2013 (less than 50 days at sea). Levels of activity in the creel fleet (more than and less than 10m) appear to vary widely, with a significant group of vessels spending less than 50 days at sea, and the largest number spending between 100 and 149 days at sea (median). However, a significant proportion of vessels - 40% - are at sea for more than 150 days.

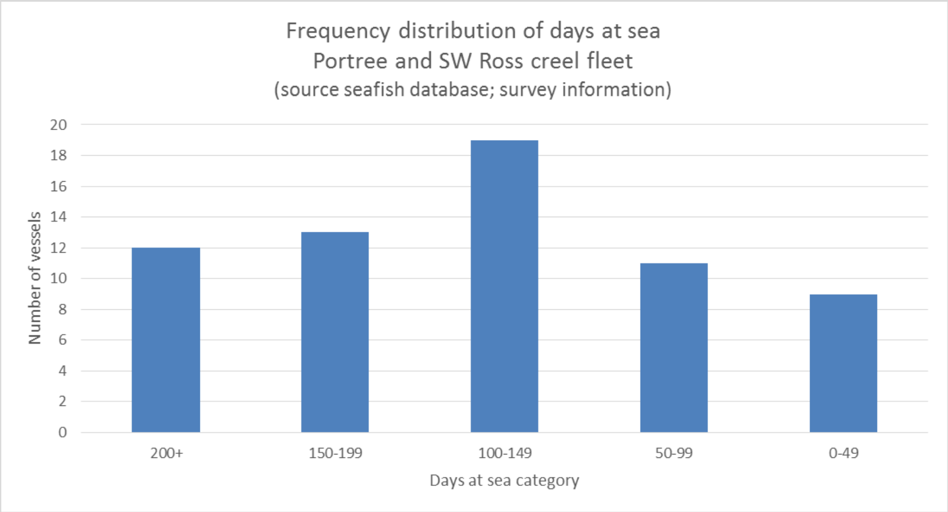

Figure 8: Fleet activity – frequency distribution of days at sea

The relationship between days at sea and length of vessel is relatively weak, but the data suggests that the average length of vessels which are at sea less than 100 days is around 7.5m, while the average for vessels operating more than 100 days is closer to 8.5m. The relationship between days at sea and power is somewhat stronger, with vessels operating less than 100 days averaging just under 60kW and those operating more than 100 days averaging just under 100kW . In other words - as would be expected – the greater the investment in the vessel, the more intensively it will be used to ensure an appropriate return.

Landings, which are closely correlated with levels of activity, are highly variable. According to the MMO database, in the less than 10m trawl category 4 vessels landed less than 1 tonne in 2013, 4 landed 1 to 5 tonnes and 3 landed more than 5 tonnes (largest being 33 tonnes). The 10-15m trawl category is clearly more active and consistent - 5 vessels landed less than 20 tonnes, and 8 landed 30-40 tonnes.

There is a far higher degree of variation in the landings of the creel fleet, as shown in Figure 9.

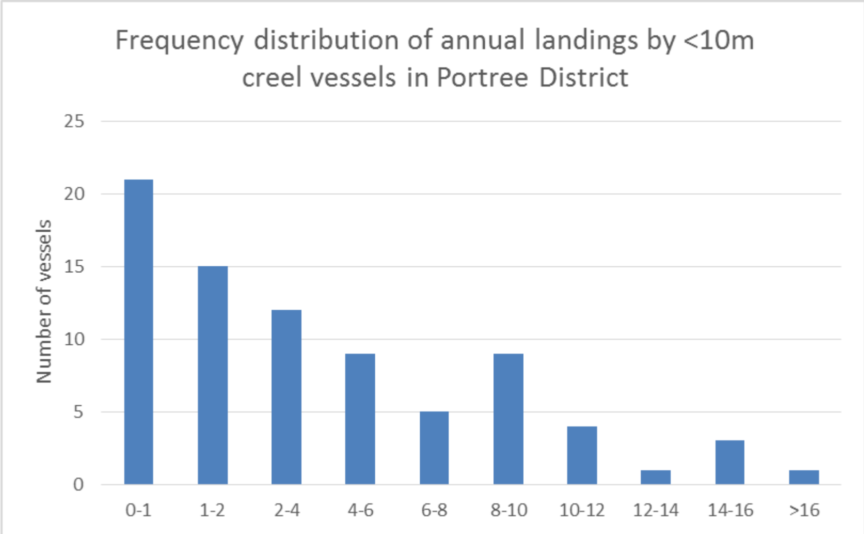

Figure 9: Fleet activity: frequency distribution of landings

Although some of these vessels may be landing additional quantities elsewhere, most small vessels will be landing locally, and this therefore is likely to be a reasonably accurate indication of activity levels. It is notable that there is no clear cut off between active and inactive vessels; rather there is a continuum of activity from inactive to highly active. Data on individual vessels, which cannot be shown for reasons of data protection, illustrates this even more strikingly. This makes it difficult to explore the characteristics of particular sub-sectors. Almost every boat has a unique economic structure and activity profile.

Although some of these vessels will be visiting from elsewhere, most less than 10m vessels will be landing locally and this presents a fair reflection of activity levels. What is immediately clear is that there is a very wide range of activity that may fulfil a range of needs from professional, specialist full time enterprises, through part time, semi-retired and “hobby” fishermen.

This continuum of activity means that it is difficult to separate rational subsidiary fleet segments, or “metier” based on levels of activity. For the purposes of preliminary analysis we have therefore simply subdivided the creel fleet into 2 different activity levels - of more than 100 das and less than 100das. However, das is an input parameter for the financial models, so more refined analysis relating to different types of enterprise can be readily explored.

7.2.3 Crew/employment

Only 1 more than 15m trawler is based in the case area, and may use a crew of 4-5 depending on season. Of the remaining 10-15m trawlers, most take a crew of 2, though 2 vessels occasionally use 3. Less than 10m trawlers normally use a crew of between 1 and 2 (average 1.4 for the case study area).

Most less than 10m creelers operate with a crew of 1 or more usually 2. Over 10m creelers typically operate with a crew of 2 or occasionally 3.

It was noted by several skippers that crew are increasingly hard to find or keep, and this, coupled with more rigorous training requirements and costs (typically £1,000) serve as a significant disincentive to take on crew on the smaller vessels - leading to an increase in one man operations.

7.2.4 Fleet economic performance

Table 5 summarises fleet economic performance, as derived primarily from the Seafish (2013) database. The actual numbers of vessels in each category are also derived primarily from the Seafish economic performance database, informed in addition by our review of the fleet at local level.

Table 5: Structure and performance profile of Nephrops fleet in Skye and SW Ross

Gear	Sub-segment	Number of vessels	Average length (m)	Power (kW)	Crew	Crew for sub segment	Average days at Sea	Total days at sea	Average Landings (tonnes)	Total landings (tonnes)	Total landed value £ (Seafish)
Creel	*Part time (less than 100 days)*	20	7.5	60	1	20	45	943	6.5	131	**264,039**
Creel	*Full Time (more than 100 days)*	44	8.5	100 High?	1-2	66	164	7,236	12.35	543	**2,603,306**
Trawl	*less than 10m*	7	9.8	89	1-2	16	148	1039	24	165	**664,849**
Trawl	*more than 10m*	10	12.1	148	2-3	25	159	1593	35	351	**1,113,827**
Trawl	*Low activity*	3	8.4	90	1-2	5	31	75	1.2	2.81	**23,270**
Visiting trawl[10]	*8.9 to 17m*	4	13.4	155	1-4						
Total for case study area		***84***				***130***		***10,886***		***1,193***	***4,669,291***

According to this analysis, total landings mainly to the area by the local *Nephrops* fleet amounts to 1,193 tonnes valued at £4.7m. This compares with total landings into the area of 1,100 tonnes valued at £6.4m as recorded in the MMO 2013 database. The discrepancy in value is probably related to the “fuzzy borders” of the case study area: there are significant landings by local vessels outwith the case study area, especially by trawlers. The value of local landings is likely to be higher, because the main marketing channels in the case study area are for high value langoustines, rather than, e.g. tails.

[10] These vessels may or may not land in the area, and have not as yet been individually identified to allow for completion of the profile. It is likely this could be done relatively easily if necessary.

Fleet profile in the case study area: main findings:

- The NW and Western Isles fleet us currently dominated by less than 10m vessels, the majority of which are 7-10m prawn creelers.
- Within the Skye and SW Ross case study area there are around 24 prawn trawlers operating regularly (including 4 visiting vessels). 10 are less than 10m, the balance more than 10m (mainly less than 15). Smaller vessels operate with 1-2 crew; larger vessels with 2-3, though some visitors may have as many as 5.
- Within the Skye and SW Ross case study area there are roughly 100 mainly prawn creelers of which perhaps 30-40 are relatively inactive; although there is a continuum of activity from near zero to highly active. less than 10m creelers operate with 1-2 crew; larger vessels may carry 2-3
- There is surprising diversity of engine power in both categories, but broadly speaking less than 10m vessels use less than 100KW while more than 10m vessels use 100-300KW
- Total income generated by landings from the fleet stands at between £4.7 and £6.4m. The larger part of both income and employment is generated by the creel fleet.

7.3 Costs and returns

7.3.1 Cost categories

To a large degree the cost categories used are defined by the data available – in other words the Seafish data categories, supported or amended as appropriate through discussions with fishermen.

For the purposes of this study we are particularly interested in the factors that affect these costs, and whether they would change if a different minimum landing size were to be agreed.

Table 6 summarizes the nature of the various cost categories, alternative measures related to these categories, sources of information, difficulties and issues associated with the category and main sources actually used for the models. In many cases several sources have been used either to cross check the validity of the figures, or in order to derive a performance related function. The table also offers an appraisal of the factors affecting the cost (in the form of cost = Function of (F) (a, b, c etc)).

Table 6: Major cost categories and sources used in the models. F means "function of"

Cost/income category	Components/indicators	Direct and indirect sources	Data quality	Main influences
Income	Landed value by vessel; quota leased out; non fishing income	MMO landings data; Seafish economic performance data; trader data	Fairly reliable with substantial cross checking	Price x quantity. Price =F(product, product mix; buyer; quantity); Quantity = F(total trawl time; size of trawl; speed/power of trawl; creel fishing days)
Capital value - tangible	Investment in vessel and gear (depreciated, or second hand value)	Industry informants; fleet register (age) MMO data; insurance premiums	Problematic. Can be accounted in many different ways for different purposes. See annex.	Size and power of vessel and quality of equipment; age
Capital value - intangible	Quota, license (may appreciate or depreciate)	Current traded value – POs; industry informants	Fairly reliable but quite variable from year to year.	Quota for *Nephrops* is not usually limiting in the case study area for <10m vessels; so license is the issue. License value = F(fleet dynamics; returns from fishery; exits/fishery)
Depreciation	Annual capital charge to set against tax	Seafish data (actual accounted depreciation); estimated depreciation based on capital investment	Problematic. Not a cash cost; may influence larger enterprises differently from smaller	F(accounting method; quality of the asset; maintenance; intensity of use)
Interest/dividends	Actual interest paid on investment loans; imputed opportunity cost of capital (e.g. interest foregone on total investment); Dividends and/or interest paid to investors or owners	Seafish data (vessel accounts); Standard estimates related to capital value Opportunity cost on estimated current value	Problematic. The actual value of the assets is uncertain (see above); the actual interest paid will depend on the financing mechanism; the imputed opportunity cost will depend on assumptions about historic investment and or current value	I = F(working capital + outstanding loan + opportunity costs (interest rates and asset value)
Fuel	Actual accounted fuel costs; imputed fuel costs based on daily consumption by size	Industry statistics (Seafish data); First principles	Likely to be accurate if good data on steaming times and days at	F=F(days at sea; power; gear; proportion of time trawling; proportion

	category (VCUs) multiplied by reported days at sea multiplied by average fuel price/litre for reference year	(consumption/hr/kW)	sea available	of time hauling and setting; distance to fishing sites)
Labour	Crew days at sea; FTE	Seafish database; MMO/MS fisheries employment data; industry informants	Likely to be highly dependent on vessel type, activity and behaviour	F(days at sea; fishing income; crew share/wage rate; number of crew)
Maintenance (repairs, gear, hire, others)	Actual money spent on routine maintenance and replacements; standard % of capital value	Seafish database; standard estimates related to capital value; industry informants	Problematic. Much maintenance undertaken by crew and may not be accounted as such; based on capital value may be misleading: capital value may be inversely correlated with maintenance.	M= F(age of vessel, engine, gear; total asset value; skills/time crew labour; number of creels[11]) *No significant differences in structures of these costs between sub-segments*
Insurance	Annual insurance cost	Seafish database; industry informants (including insurance companies)	Premiums may be related to history rather than performance; maybe higher for an unreliable vessel v high cost vessel	F(boat/gear value; track record?)
Bait	Accounted costs/yr; costs per day or trip; costs per pot/set	Seafish database; industry informants	Some fishermen may catch their own bait.	F(pots set/hauled; bait/pot; cost/bait)
Boxes and ice		Seafish database; industry informants		F(landings)
Commission, harbour dues, subscriptions and levies (selling costs)		Seafish database; industry informants		F(landings) Significantly higher for trawlers (ca £7K) than creelers (ca . £800) = ca 5* as much per unit landed value
Other fishing expenses, including commission, provisions, shore labour, quota leasing, days purchased, crew travel		Seafish database; industry informants		Standard % of income?

[11] Creel maintenance is a substantial task and it may take a couple of months to pressure wash and repair 800 creels

The following are the key parameters and characteristics that are likely to affect costs and returns, some of which will be used to develop model relationships and explore impact on costs of any changes in vessel behaviour or characteristics:

1. Age of vessel
2. LOA
3. Power
4. Vessel capacity units
5. Days at sea
6. Distance to fishing grounds
7. Distance to landing station
8. Trawls/das
9. Hours/trawl
10. Catch/trawl hour
11. Pots hauled/das
12. Pot soak time
13. Catch per pot hauled
14. Fuel consumption (function of the above)
15. Labour (function of the above)

7.3.2 Summary of costs by metier based on Seafish database

Using local information on vessels and vessel characteristics along with matching data in the Seafish economic performance database, we have been able to profile the financial characteristics of the different fleet sub-segments operating in the case study area. Unfortunately it was not possible to separate actual reported individual vessel performance data from performance data imputed to a vessel based on performance/cost structure averages for the sub-sector. As such the cost structure of sub-sectors or "metiers" (such as less than 10m creeler; less than100 days at sea) could not be derived directly from the database. Rather the data provides a bench mark for the higher level fleet sectors (as generated in the Seafish annual summary publication). This bench mark has been used as the starting point for developing more locally appropriate and parameter responsive models as presented in section 10 and Annex 3.

Baseline costs and returns: main findings

- Cost categories are reasonably standardised, and this research follows as far as possible the categories used in the Seafish economic performance database.
- Estimation of capital and investment related costs is problematic for a variety of reasons, and both the accounting of those costs and the impact on enterprise behaviour is likely to vary with the size and investment structure of an enterprise.
- Labour, fuel maintenance, and capital related costs (depreciation and maintenance) dominate production costs of all types of fishing enterprise, and the relative proportions of these costs are surprisingly similar between creelers and trawlers.
- Production costs (per kg landed) in the creel fleet appear to be only slightly more than those of the trawl fleet, which, given the much higher value of the product, implies significantly higher profit and value added.
- The Seafish economic performance database reflects the performance of the main sub-sectors, and does not allow for further meaningful disaggregation of the data into subsidiary metier or enterprise categories. Nonetheless derived data been used as an important benchmark for the development of the baseline models as presented in Section 10 and Annex 3.

8 IMPLEMENTING AN INCREASED LANDING SIZE – TECHNICAL MEASURES AND FISHING STRATEGY

This section explores how an increased landing size might be implemented from a technical perspective, and the implications for fishing costs.

There is no question that this is feasible. A significantly higher minimum landing size is implemented in both Danish and French *Nephrops* trawl fisheries. In both cases this had led to some improvements in gear coupled with relatively high discard rates.

In order to understand the possible impact on costs of any changes in fishing practice, it is necessary to explore in some detail the nature of current fishing practices.

8.1 Current fishing practice

8.1.1 Trawlers

Most smaller trawlers fishing in the case study area use low headline coverless “scraper” trawls (TR2) with 80mm or 100m (usually on larger trawls) diamond mesh codend. The low or open headline is used because *Nephrops* do not swim high to avoid a net (unlike some whitefish species) so a low net improves selectivity for prawns over whitefish. Some use selective net modifications to gain access to conservation credits scheme, including most commonly a 120mm (up to 200mm) square mesh panel.

Larger trawlers that normally operate in the North Sea usually also use 160mm diamond mesh lifting bags made from 5 mm double PE twine. These are attached top and bottom and encircle the codend to prevent it from bursting when the trawl is hauled on board.

In recent years most of the larger vessels have shifted to “twin rig” arrangements. This is largely because *Nephrops* do not respond to “herding” by well-spaced net “wings” or the disturbance caused by trawl boards. If they find themselves too far from their burrows to make an escape they may swim up a little to avoid the ground rope (Main and Sangster 1985) and then tumble backwards into the net, though they may make the odd swimming spurt (tail flicks). This means that prawns not in the track of the main net will tend to be released through side panels or over the ground gear. Twin rigs greatly increase the width of the catching track compare with single trawls. While most of the trawlers in the case study area are still single riggers, there are signs that this is changing, and most visiting vessels are already equipped with twin rigs.

Most trawlers based in the case area fish for a day before returning to port. This may be a long day however – usually as long as it is light (4:40 am to 10:30pm in spring/Summer). However, some of the medium size and larger trawlers may go to sea for 2, 4, 7 or even 10 days, and make interim landings wherever convenient, sometimes outside the case area (e.g. to Mallaig, Stornoway, Ullpool). Longer trips are sometimes necessary in winter because of the closure of the grounds to the south of Skye (October-March) under local bye laws. In summer equally it may make sense to maximise returns in good weather and long days. Larger visiting trawlers may operate continuously in the North Minch in Spring/Summer with a changeover crew every 7 days.

Fishing is concentrated in prime fishing grounds as indicated by skippers during discussions and demonstrated in the maps produced under the Scotmaps project (Figure10). One skipper suggested that 50% of trawled prawns came from the “Shiants Triangle” (North of Skye) although the maps suggest high concentrations of activity also in Lochs Dunvegan and Snizort, to the northwest of Rhona, and around the Isle of Rum. There is also highly localized and concentrated effort close to some closed areas.

The reason for the concentration of effort is partly related to the spatial variation in abundance (and occasionally the size) of *Nephrops*, but also to the distance from port. Many of the smaller vessels are day fishers, and this means they will fish inshore close to home port or landing station.

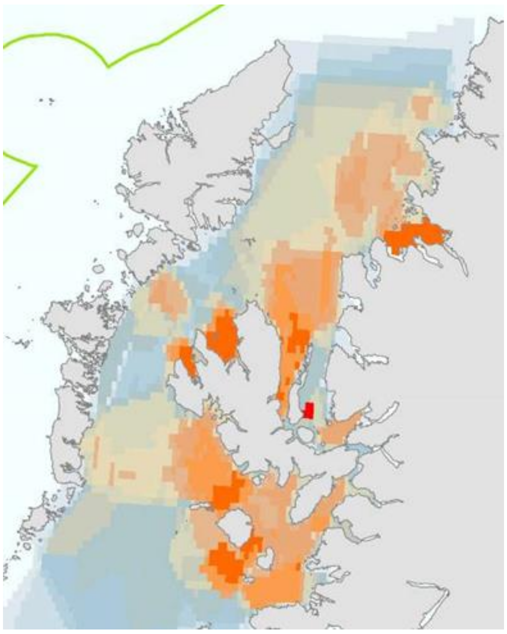

Figure 10: Value of trawled Nephrops caught in different fishing grounds (Source:Scotmap)

Fishing activity is typically at its most intense in daylight hours in Spring and Summer, declines slowly over the autumn and increases again before Christmas prior to a relatively inactive period in January and February. Catch rate varies according to location, weather, season, tides. It is extremely hard to pin down the nature of this variation, but there is no doubt that there are substantial differences in the performance of vessels fishing in the same overall areas, and it must be assumed that highly skilled skippers are able to find the best fishing areas.

Trawls are typically towed for 3 to 4 hours (occasionally up to 8) at 2.6 to 2.8knots, although a shorter and slower tow duration may be used for the last shoot of the day to maximize product value (fewer damaged prawns). This means that most trawlers achieve 2 to 3 x 3 to 4 hour trawls per day – or 6-12 hours effective trawling per day at sea, depending on season and crew. When using shorter tows, roughly 50-60% of prawns are landed live on deck. Work by Glasgow University suggests that tows should not exceed 4 hours, that the gear should be hauled to the surface relatively slowly (i.e. 30 mins) and that, for best results, the catch should be sorted quickly (cited in Moody Marine, 2009).

In most cases prawns are size graded whole into fish boxes, or tailed if they are small or damaged (roughly 50:50) then dipped in sodium metabisulphate before landing to prevent bacterial/fungal degradation (e.g. “black spot”). Once dipped a prawn (live or dead) cannot be sold live.

If prawns are small (less than 32mm carapace) or damaged, they are tailed and the heads discarded overboard. These are destined primarily for the “scampi” market (see section 9).

Some of the smaller trawlers may tube their best live prawns, but this is unusual, and it is exceptional for larger trawlers to do this. Where a trawler is seeking to land significant quantities of live prawn they may not wish to sort them, and may leave this to a buyer, although this will have a price penalty. In this case it is likely that the prawns will be stored in a live facility for a few days to recover, and allow for removal of dead prawns prior to shipping. In some cases they are chilled down overnight in a vivier lorry and may be resorted following morning before transport.

Handling time on board is likely to increase where fishers specifically target whole live prawns. There will be a requirement for reception hoppers, a good size sorting table and holding tanks. Strong *Nephrops* in good condition are selected and placed into individual compartments within a tube matrix, ideally in a single sorting operation to minimize handling, and placed in the tanks.

Some trawlers land a small amount of whitefish as bycatch (monks, haddock, skate). For example, one skipper interviewed typically lands 2-3 boxes a day. While many skippers would like to catch more whitefish, especially in late summer and autumn when *Nephrops* catch is poor, this is difficult because of quota and gear. Gear to catch whitefish efficiently would have to be TR1 – i.e. 120mm. Since the cod rules only allow vessels to carry one type of gear, gear changes become costly and inflexible.

8.1.2 Creelers

A typical creel used in the case area is a 22 inch double entrance D-creel with 38 mm mesh (though some are 25-30mm), baited with salted herring or sometimes locally caught mackerel. A set of creel gear usually comprises creels spaced up to 16 m apart on lines or 'fleets' that can accommodate between 40 and 120 creels per line. A typical smaller 1 man full time creeler would use 1 or 2 “sets” of 400-500 creels; a larger vessel with two crew might use two sets of 6-800. In the Western isles they use more.

A one man vessel can service up to 500 creels per day; some say up to 600. A single boat with two crew can haul between 800/day and at the extreme 1200. These numbers appear to have increased over time, although the technology has changed little, suggesting increased effort. Adey (2007) cites Howard (1989) as reporting between 400 and 1,000 creels/vessel/day. It is suggested by skippers that we have now reached the physical limit of what can be done on a single vessel[12].

Most fishers are out for a day – typically around 7-11 hours - but some occasionally go out for 2 days to deeper water in summer. This practice means that pressure is most intense on accessible fishing grounds. Figure 11 shows the value of creel prawns fished from different areas, and this highlights the intensity of fishing in key nearshore areas – and especially in the trawl free zones. Most skippers do not wish to travel for more than 1 to 1.5 hours to fishing grounds, and one skipper suggested that creelers would rarely work outside a 15 mile radius of base due to time and cost constraints. This limitation has the advantage of reducing conflict with mobile gear.

A common practice is to begin hauling the furthest sets first and work back steadily toward the landing site, thereby minimising delay getting the prawns landed.

[12] Note that a creeler could not haul two sets of a gear at one time using double gear and crew, since sets are spaced to minimise mutual interference.

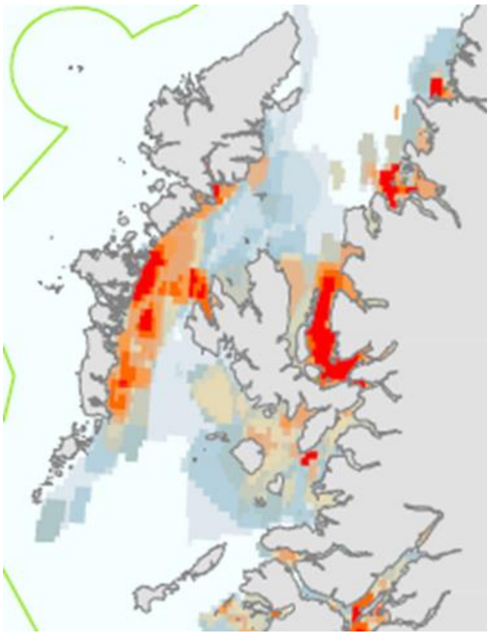

Figure 11: Relative value of creel prawns caught from different areas (Source:Scotmap)

Creels must be serviced by removing the prawns and any old bait, and re-baiting. Throwing old bait overboard may encourage seagulls who will also take discarded live prawns, so some creelers collect old bait as they go and discard separately at the end of the trip. Some creelers may also take care when discarding small prawns by distracting seagulls with old bait and then dropping the prawns carefully over the side.

Creels are usually hauled, rebaited and reset in close proximity to save time and fuel (Adey 2007). A fleet or set of creels is usually allowed to lie for 1 or (more usually) two days, though significantly longer "soak times" are not uncommon (McLay 2008). One skipper suggested that most haul every 2-3 days based on 2 sets of gears. Long soak times may relate to establishing "turf" rather than fishing efficiently. Bait is unlikely to last more than 2 days (Finlayson pers. com). One skipper suggested that a longer soak time is necessary in deeper water, where there are fewer, but larger prawns.

There is anecdotal and behavioural evidence that longer soak times result in larger prawns (the smaller prawns are more likely to escape and/or be deterred by presence of large aggressive prawns in or near the creel). So while a 2 day soak is likely to yield more and bigger prawns, it is unlikely to be double that associated with a one day soak. In order to implement a 2 day or more soak time most skippers would prefer to have double the number of pots they can haul in a day (1,000 to 1,200) so that they can set and haul 50% of these every day with a 2 day soak time. This represents a substantial investment relative to that required for a one day soak time.

Market size prawns are placed in tubes (dry) until the full set of creels has been serviced after which they are stored in seawater tanks where they remain for 6-10 hours until landed (occasionally they may simply be slung over the side) . They are then held overnight in chilled seawater tanks on land or in a vivier lorry, or in the open sea overnight (12 hours). In the morning they may be resorted before transportation by vivier lorry, or repacked into tubes in polystyrene boxes, and chilled with ice or ice packs (no direct contact), before transportation by van and aeroplane to UK or European markets.

Fishing effort is partially seasonal, and as for the trawlers, activity is greatest in the spring and summer and shortly before Christmas. Bad weather has a more severe impact on creel boat activity than on the generally larger trawlers. Many skippers fish very little in November.

As noted above, there is significant variation in size and density of prawns between areas. Some skippers suggest that the main influencing factor is depth; Adey (2007) suggested that substrate is a key factor, with fewer larger prawns found on harder substrates.

Figure 12, taken from Adey (2007), shows the activity of a typical creeler during a day's fishing.

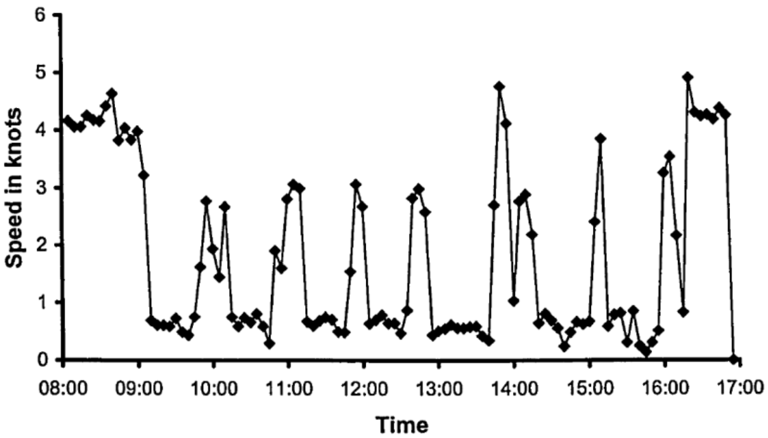

Figure 3.1 – Variations in speed (determined from GPS-records) of a creel fishing vessel for a typical day in the Inner Sound area in March 2004.

Figure 12: Activity pattern of a typical creeler (Source Adey, 2007)

This chart may be interpreted roughly as follows:

- Steam to fishing grounds – 1 hour
- Haul, sort, bait – 30-45minutes
- Shoot – 30 minutes
- Hauling and shooting repeated up to seven times
- Steam to landing site – 30-40 minutes

During hauling, the engine may be on standby, in intermittent use (depending on tide and wind) or in some cases completely off. In terms of proportions of time this would correspond to roughly 20% full steaming; 35% hauling (10% full steaming); and 45% setting (roughly 60% of full steaming)

Time spent at sea (das) is highly variable, but a professional fisherman will typically spend 160-220 days at sea. Last year the weather was bad and it was hard to do more than 160. A typical year might be 180.

The case study area includes Torridon, which was the focus for an MSC certified Nephrops creel fishery in the late 2000s[13]. Several conditions were associated with the certification as

[13] Unfortunately it was not possible to maintain the certification, primarily because there was no clear mechanisms for controlling access and therefore effort.

described in the case background section. Of particular relevance to this study is the use of escape panels by fishermen who signed up to the management group code. The escape panels had gap width 22 mm and overall length 96 mm designed to allow escape of prawns up to 40mm CL. These panels may also facilitate escape of smaller crabs thus reducing bycatch. Escape gaps as large as 43mm have been trialled. It should be noted however that *Nephrops* creels in any case tend to select the larger animals (Bjordal, 1986; Tuck & Bailey, 2000; Eggert & Ulmestrand, 2000; Bell et al., 2006 cited in Adey 2007).

Current fishing practice: main findings

- The trawl fishery for prawns in the Minch is relatively clean, in part reflecting the decline in whitefish, though increasing numbers of rays and dogfish are now being caught
- Most visiting trawlers are now twin riggers, and although there is significant concern and resistance at local level, an increasing proportion of larger local boats are switching to this gear.
- Fishing by creelers is normally based on single day fishing trips, so is highly concentrated close (within 15nm) to home ports/landing sites and/or in trawl free zones.
- Fishing by trawlers is more widely dispersed but still relatively concentrated in good fishing areas and/or shelter and/or close to landing sites.
- Trawlers occasionally land whole live, and several boats have tanks; but this is unusual because it is time consuming, and the cost structure of larger vessels favours volume over unit value.
- There are basic limits on the number of creels that can be hauled by a vessel in a day, ranging (roughly) between 500 for 1 man to 800 for two man vessel.
- Since many fishers prefer to leave pots in for 2 days (soak time) many skippers consider the ideal number of creels to be 1,000 to 1,600 creels, so that 500 to 800 can be set and hauled each day. Creels may be left for longer for strategic or logistical reasons.
- Size and sex of catch varies significantly through time (long term, and seasonally) and dependent also on location, substrate, depth, tide, weather etc.
- In general terms larger prawns tend to be found in deeper water and close to boundaries of closed areas
- Many discarded prawns are lost to gulls, but this can be reduced substantially through good practice.

8.2 Catch profile using existing gears

Basic information is available on the composition and size profile of the catch using existing gears from the work of Marine Scotland Science (MSS), and from especially commissioned studies in support of MSC certification of the Torridon Creel Fishery and the North Minch Trawl Fishery. Data is also available from traders that shows the size frequency of grades landed.

8.2.1 Size, sex and seasonality

The following are some key characteristics of the **creel** fishery according to McLay (2008).

- The greater part of the overall catch is male (67%)
- XXL, XL and large (more than 45mm CL) *Nephrops* sizes are predominantly male
- Catch of females is highest in the summer (quarters 2 and 3) averaging between 40 and 60%
- Berried and non-berried females constituted 6% and 26% of the female catch respectively;
- The proportion berried females is highest in September-December (up to 16%)
- Catch of males peaks in January-March when they may comprise more than 90% of the catch

And for the trawl fishery

- Overall 46% male and 54% female
- Berried females a small proportion of the catch - less than 5%
- Of specimens more than 35mm males comprise more than 50%
- The catch includes some less than 25mm

Note however that the proportion of males and females is highly seasonal in the trawl fishery, with far more females appearing in the catch when they emerge from their burrows to spawn in the spring and summer. Some of the data presented by ICES (2013) suggests that the ratio of males/females in the North Minch Fishery may on average be higher than that given above.

8.2.2 Length frequency and sex

Figure 13 (from McLay (2008)) gives a size frequency distribution of Nephrops caught in the creel zone 2001-2006, and figure 14 shows frequency distribution for the trawl using standard commercial gear.

For the creel fishery, median carapace length of males is around 43mm, and females 40mm. Only a very small proportion (around 4%) are less than the minimum size for live sale (around 32mm in the Spanish market), less than 0.1% below 25mm and insignificant numbers below the current 20mm West Coast MLS.

The Effects of the Creel and Trawl Fishing Zones on *Nephrops* Stocks in the Loch Torridon Area

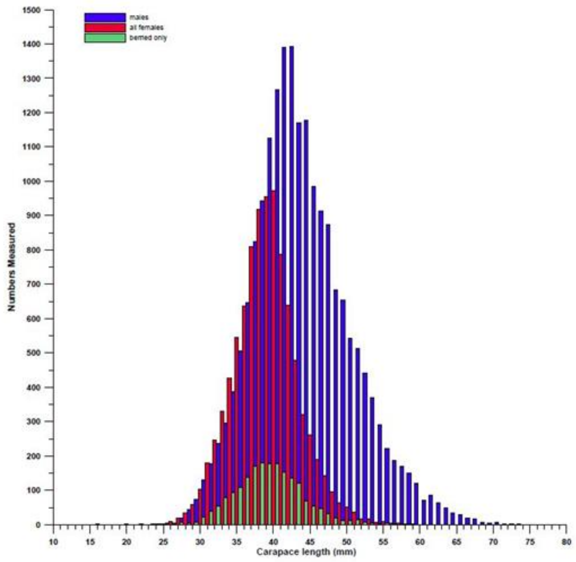

Figure 3.19: Standardised length frequency distribution of *Nephrops* catches sampled in the creel zone from 2001 to 2006.

Figure 13: Length frequency of creel caught Nephrops in Torridon Area Creel Zone (source McLay 2008)

In the trawl fishery, median carapace length is around 29mm for females and 31mm for males. Just under 50% of the catch is under 32mm (typical minimum for whole fresh). Around 10% are less than 25mm (MLS in the North Sea), and a mere 1% is less than current West Coast MLS (20mm).

The Effects of the Creel and Trawl Fishing Zones on *Nephrops* Stocks in the Loch Torridon Area

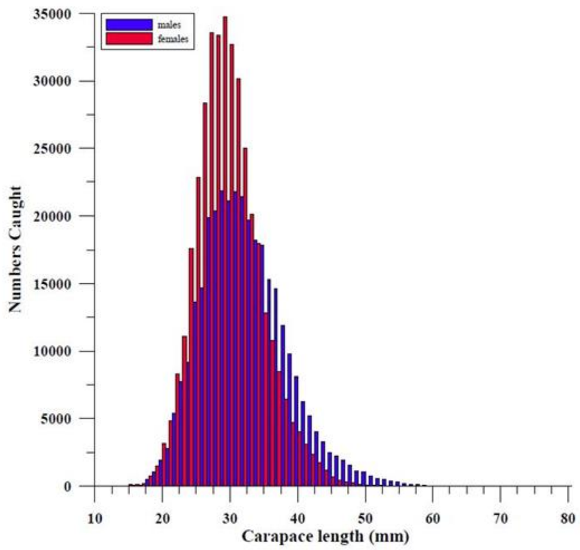

Figure 3.20: Standardised length frequency distribution of *Nephrops* sampled in the trawl fishery (in the trawl and mixed fishing zone) raised numbers caught, 2001 to 2006.

Figure 14: Length frequency of trawl caught Nephrops in the Torridon Area trawl zone (Source McLay 2008)

Data provided by Adey (2007) for the whole West Coast across all areas and months paints a broadly similar picture for creels, with median size of males in the creel fishery of 42mm and females 39mm and insignificant quantities caught below either the 25mm (East Coast) or 20mm (West Coast) MLS. His data for trawls however suggests a rather larger average size profile.

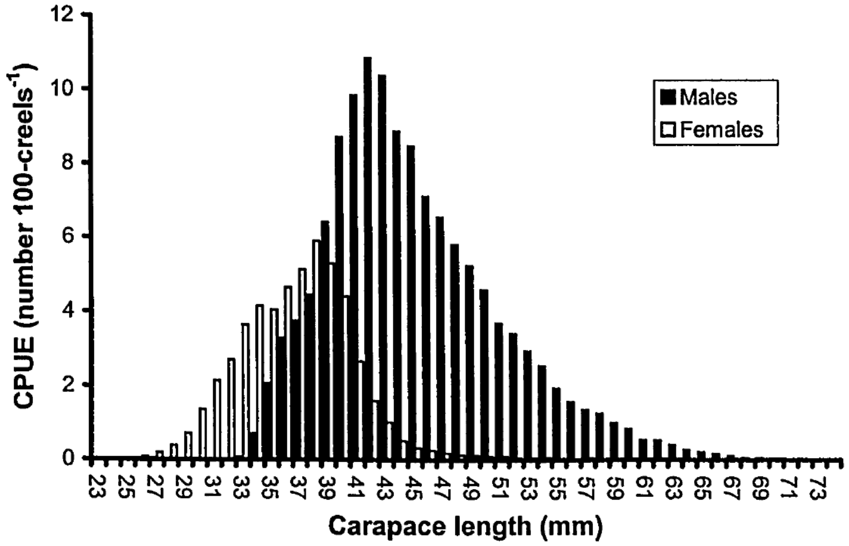

Figure 2.9 - Length-frequency distributions of male and female *Nephrops* standardised to mean number caught per hundred creels (CPUE), aggregated across all areas and months (n=25 645 creels).

Figure 15: Size Profile of West Coast Creel caught Nephrops (source: Adey 2007)

Data is also available from individual vessels and traders. The following shows the typical proportion of different commercial size categories landed by trawlers in Skye, according to local sources. These estimates suggest that the size profile at the present time from Skye and the NW West Coast may be rather smaller than that suggested by Figures 13-15.

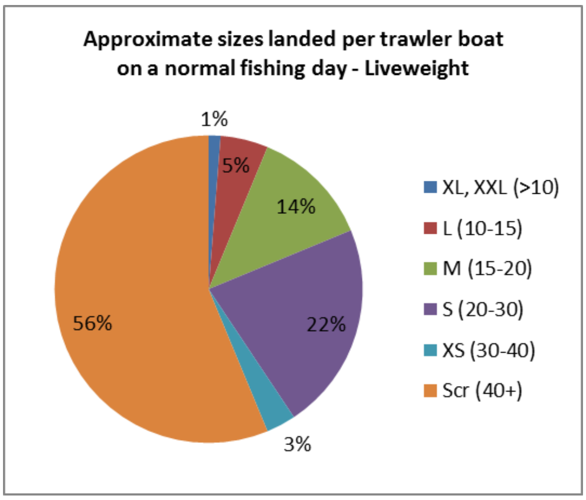

Figure 16: Typical proportion of commercial product categories landed by Skye trawlers

The question then arises as to what happens to these various sizes of prawn. In the creel fishery there is some variation in the fate of prawns caught between areas, and this may relate to both the size profile of the catch, and the demands of buyers. The minimum size for a live prawn is 32 mm – although for some markets – and especially Spain, demand for live prawns less than 40mm may be very limited. This suggests that in all areas animals less than 32mm will be discarded (less than 5% of the catch), but in some areas, discarding may be extended to animals less than 40mm – comprising 30% or more of the catch (e.g. Tuck and Bailey 2000) – although this could be significantly reduced through the use of escape hatches. In the Torridon fishery where escape hatches are used, up to 20% the catch may be discarded (Moody Marine 2008). However, this appears to be contradicted by skippers we interviewed who reported that most of 'discarding' happens through the escape gaps whilst the creels are on the seabed, leaving only the berried females and heavily encrusted *Nephrops* as discard.

For trawlers the fate of the prawns caught is more complex. MSS has undertaken much work over the years on the North and South Minch Creel fishery under its observer programme, and the fate of prawns landed at different sizes has been estimated. McLay et al (2008) observed the trawl fisheries in the North (FU11) and South Minch (FU12), where the majority of discards range from 18 – 30 mm CL, with a mode of 25 mm CL. More detailed and up to date results relating to the North and South Minch functional units are shown in Figure 17 from Drewery at al (2015). Fates are illustrated as a percentage of three possible for each carapace length grouping. Individual trawlers or groups of trawlers may exhibit significantly different discarding behaviour dependent on the size profile of the catch, market forces, seasonal forces, working logistics and individual vessel practice.

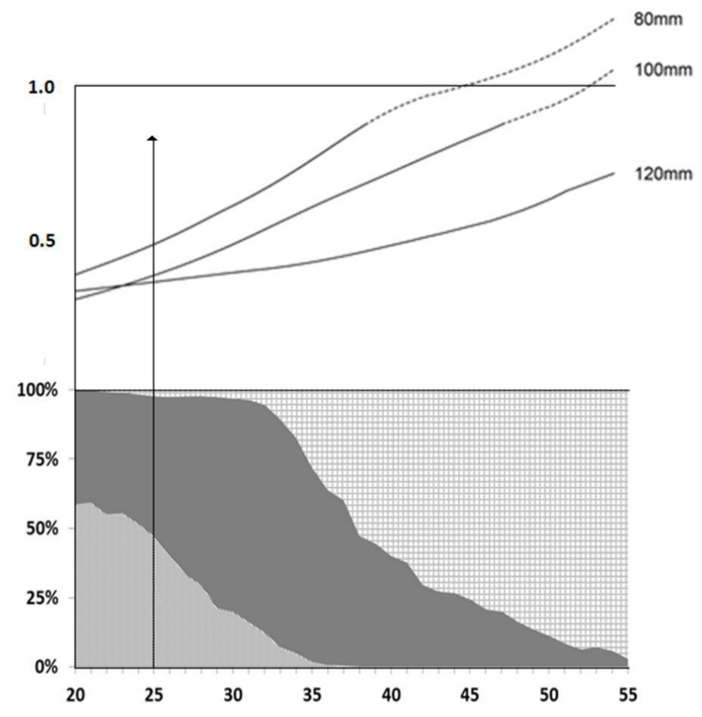

Figure 17: Fate of prawns N and S Minch Trawl Fishery 2013 (80mm and 100mm codends) (Source: Drewery et al 2015)

Note: light grey: discarded, dark grey: landed as tails, cross-hatched: landed as whole.

It is also worth mentioning here the fate of discarded *Nephrops*. Discard mortality is widely regarded as low in the creel fishery, since they are usually in prime condition when released. However, mortality can be high from gulls (reported as 9% by Moody marine 2008 for example), and from other predators as they fall through the water column and before they can find a burrow. Discard mortality is likely to vary significantly according to practice and ecological conditions. Most creelers we talked to were of the view that improved release practices have greatly reduced gull predation losses in recent years. Discard mortality in the trawl fishery on the other hand is regarded as relatively high: ICES (2013) assume 75% discard mortality.

8.2.3 Catch adjusted to landed product ratios

A spreadsheet model has been developed that allows for the baseline catch profile in terms of numbers (e.g. as shown in figures 13-16) to be adjusted to proportion of landed weight by product category. This can then be converted into landed value (per kg) by multiplying the product array by the value array as presented in section 9. For the creel fishery this is relatively straightforward since almost all the product is live whole. For the trawl fishery an adjustment has to be made for the fate of the prawns (as illustrated in figure 17) and the tail yield. The catch profile can then be modified to explore the possible impact on returns per kg of product of introduction of MMLS, or changes related to modified gear or fishing practice.

Results based on catch profile corresponding to figures 13 and 14 are presented in Annex 2 for both creel and trawl fisheries.

Catch profile of existing gears: main findings

- There is a significant difference in the size and sex profile of prawns landed by trawlers and creelers. This is likely to vary significantly from location to location and year to year.
- Overall, the greater part of the creel catch is male (ca 67%) and the proportion is highest January to March. The proportion of females is highest in summer and autumn. Berried females comprise 6% of the catch overall but up to 16% in September to December. Since females are generally smaller (mostly less than 45mm CL) than males, a higher proportion are discarded.
- In the trawl fishery females comprise 54% of the catch, but the proportion of berried females is less than 5%. The majority of larger prawns are male.
- The median CL of prawn caught in the creel fishery is around 42mm with only a very small proportion (less than 4%) smaller than the minimum fresh or live market size (32mm) and insignificant numbers less than 25mm. Prawns under 32mm are normally discarded and the rest are tubed for live sale
- In the trawl fishery, median CL is around 30mm. Just under 50% of the catch is under 32mm (typical minimum for whole fresh or live). Around 10% are less than 25mm (MLS in the North Sea), and 1% are less than West Coast MLS (20mm). Of the prawns under 25mm roughly 50% will be discarded and the rest tailed. Of those 25-32mm around 26% will be discarded, 72% will be tailed and a few (perhaps 2%) will be landed whole. Above 32mm around 35% will be tailed and 65% landed whole
- A spreadsheet model has been developed for the conversion of catch size profile into product size profile that can be adjusted according to differing assumptions and scenarios, and used to generate expected fishing income estimates. Sample output can be found in Annex 2.

8.3 Modifications to *Nephrops* trawls to reduce catch of smaller prawns

An increase in MMLS in the trawl fishery could be achieved through the use of nets with various grids, panels and other or devices to allow smaller specimens to escape, and/or use of larger mesh size or square mesh in various parts of the net including the codend.

This is a complex subject – the configuration and design of nets is almost infinite, and the findings of gear trials are inevitably compounded by the effects of location, season, weather tide, fishing speed or pattern. Developing and testing new gear is a time consuming and expensive process, and changes to gears can never really be fully tested until they become commonplace in a fleet. The task is particularly difficult for *Nephrops*, because their complex shape, long appendages, and relatively passive movement means that they do not respond in a simple way to changes in mesh size or the use of panels and grids.

Nonetheless, in order to make any predictions about the feasibility and economic impact of any change in MMLS, it is necessary to derive approximate estimates of possible changes in catch size profile that might be achieved with different gears. A fairly thorough review of the literature from the UK and abroad is therefore necessary.

There is a substantial literature from Scotland, Ireland, Scandinavia, France and Portugal relating to performance and selectivity of different *Nephrops* trawl designs. The main incentive for this research has been to increase selectivity for *Nephrops* relative to whitefish, and especially cod, since these species make up a significant component of bycatch, especially in the North Sea. The new CFP "landings obligation" has further stimulated this research. Many of these trials however also examine the impact of net modification on *Nephrops* selectivity, and are therefore relevant to this study. In addition, several studies (in Scandinavia, France and Scotland) specifically address gear modifications to improve *Nephrops* size selection. It should be noted that the minimum landing size (MLS) of *Nephrops* in the Scandinavian Kattegat and Skagerrak regions is 40 mm carapace length compared with 25 mm CL in most of Europe and 20mm on the West Coast of Scotland. In France, the French Fishermen's Organisation has set their own MLS of 35mm carapace length. In both cases this has resulted in high discards and stimulated research on possible gear modifications to reduce catch of less than MLS animals.

Unfortunately improving net design to be more selective for larger *Nephrops* is difficult. Catchpole and Revill (2007) note that *Nephrops* trawls exhibit a wide selection range (SR[14]). This is attributable to the general behaviour and morphology of the species—the many appendages get caught in the meshes and other organisms in the trawl, causing the retention of small individuals even where larger mesh sizes or square mesh configurations are used.

Furthermore, results from different trials (in different places or at different times) tend to be highly variable. Madsen and Valentinsson (2010) note that "Owing to the different methods and materials used, the areas fished, the between-trial variation in the catch composition, the species size frequencies of the fish encountered, and the environmental conditions, it is not possible to make direct comparisons between trials". It is clear therefore that the confidence with which results can be applied to different situations is low, and the costs potentially high.

[14] Selection range (SR): The difference in length between an animal that has a 75% probability of retention and that with a 25% probability of retention. This is a measure of the sharpness of selection i.e. the shape of the selection curve.

The following reviews the main modifications that have been made and their effects on the size distribution of the *Nephrops* catch. This is derived mainly from two important reviews: ICES (2007) and Madsen and Valentinsson (2010). Additional studies and perspectives have been added where relevant.

The main trawl modifications can be categorized categorised as:

- General design and set up
- Codend mesh size and mesh type
- Codend extension (various configurations)
- Square-mesh panels
- Separator grids
- Separator and guiding panels

8.3.1 General design and setup

Some recent work has aimed at developing trawls with increased catch rates of *Nephrops* and reduced catch rates of fish by reducing the distance between doors and using longer wings, lower trawl heights and large-mesh top panels (LMT). It is unclear what effect these trawls may have on *Nephrops* catch size distribution.

8.3.2 Codend mesh size and mesh type

Some early work by Main and Sangster (1984) provides an insight into the effect on size selection of 70-80 and 90mm bottom codend mesh. This suggests that codend mesh is not a good predictor of size selectivity. Retention of less than 25mm *Nephrops* in 70, 80 and 90mm codend mesh size was 20%, 28% and 19% respectively. In other words, increasing mesh size does not necessarily result in reduced catch of smaller prawns. Madsen et al (1999) also note that selection ogives of *Nephrops* are less `knife-edge' than for fish species, and an increased mesh size will result in a considerable loss of individuals over MLS. This probably relates to the complex shape of prawns and the ease with which they can be caught once in the water column.

Other studies have also shown that increased mesh size may lead to significantly increased escape of larger prawns as well as smaller. For example a Scandinavian study tested an increase in mesh size from 90 to 120 mm and found a reduction on the catch of legal sized prawns (more than 40mm in Denmark) of 1/3 (Madsen and Valentinsson 2007). Frandsen et al (2011) tested a new codend concept combining square meshes and diamond meshes in a four-panel configuration and with a 5 m long 70 mm square-mesh panel inserted in the lower panel of the codend. Numbers of *Nephrops* below Scandinavian MLS (40 mm CL) were reduced by approximately 37% but the expected weight of marketable catch was also reduced by 21%.

As part of a series of trials undertaken by IFREMER mainly focused on grids (see ICES, 2007) three trials were carried out with larger meshes in the codend (80 mm PE instead of 70 mm PE). They found escape of small *Nephrops* (less than 9 cm) was around 30% and no losses were recorded on commercial sizes. This appears to contradict findings by other studies, but the effects are compounded by the use of grids (see below).

Modification of mesh type/shape may be more effective. There is some evidence (e.g. Frandsen et al. 2010) that use of a square-mesh codend increases size selectivity for *Nephrops*. Codends constructed with the diamond meshes turned 90° may also increase selectivity (and is relatively cheap) but it was found that retention of *Nephrops* above Danish MLS of ≥40 mm CL was reduced considerably, especially during haul back.

Of particular relevance to this study, Drewery et al (2015) recently conducted trials in the North and South Minch to examine the effects of codend mesh size and twine number on the selectivity of Nephrops trawls. They compared:

- 80 mm diamond mesh codend of 4 mm single Brezline (PE) twine
- 100 mm diamond mesh codend of 5 mm double Brezline (PE) twine
- 120 mm diamond mesh codend of 5 mm double Brezline (PE) twine

Brezline was used for the trial gears – a polyethylene twine that has higher abrasion resistance, mesh stability, longevity and stiffness. This may reduce selectivity since it may not open as easily as conventional mesh. In order to simplify comparisons and focus only on the issues of mesh size and twine material, the trials were undertaken using twin rig trawls (control and experimental for each rig) but without the use of lifting bags, chafers (used on 120 mm codends) and square mesh panels (fitted on all trawls). Nonetheless this study offers important insights into how size frequency of catch may be affected by mesh size and materials. The control consisted of a 40mm mesh codend designed to catch all target species.

They found that catch rates and size of *Nephrops* in the 3 test gears differed significantly from each other as presented in Table 7 and Figure 18.

Table 7: Effect of codend mesh size on relative retention

Carapace length (mm)	retention 80mm	retention 100mm	retention 120mm
20	39%	31%	33%
35	77%	61%	43%
38	87%	68%	46%
54			71%
ret. all	79%	67%	47%

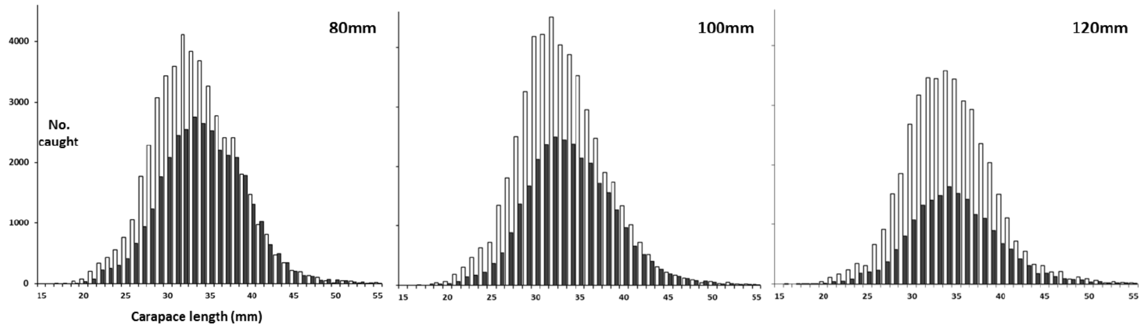

Figure 18: Comparison of length frequency of Nephrops caught in control (white) and test nets (black). Source: Drewery et al (2015)

They also found reduced bycatch of whiting and haddock as mesh size increased.

For the purposes of our analysis we are interested in both the reduction in landings and the shift in commercial size profile. This particular example suggests that an increase in mesh size results in a significant overall reduction in catch of around 40% as mesh size increases from 80mm to 120mm. It might be expected that the impact on larger specimens would be less, but in fact the evidence shows a greater impact on the larger size classes (more than 40%) compared with smaller size classes (e.g. 25-30mm) of around 15%. This is probably related to the fact that the catch of smaller specimens is limited not by mesh size, but by other behavioural factors.

Skippers perspective

Skippers themselves noted a significant decrease in catch of good quality smaller prawns when mesh size increased to 80mm. Nonetheless most skippers of larger vessels choose to use 100mm nets, in part to allow access to the conservation credits scheme, but also because there is a general view that the larger mesh works with more power and longer hauls, and the smaller mesh is better for smaller vessels. This reinforces the view that slower smaller vessels are more selective. One skipper suggested it may be appropriate to recommend 80mm for vessels less than 200HP; 90mm for vessels 200-400HP; and 120mm for vessels of 500-1000HP.

Skippers were of the view that significant increase in mesh size may lead to between 20 and 50% loss for less than 12m trawlers, and this was not therefore a viable option. This appears to be confirmed by the trials reported above.

Increasing codend mesh size is unlikely to deliver selective benefits in terms of lower retention of smaller prawns compared with larger. It will simply reduce fishing efficiency overall. The evidence relating to the use of square mesh in the codend remains very limited.

8.3.3 Sorting box

A 4 panel sorting box set in the entrance to the codend was found to reduce whitefish catches, but the selection curve of Nephrops was not different from a standard diamond mesh codend (Madsen et al., 2010)

8.3.4 Top panels

Large 200mm square mesh top panels may be effective at releasing fish bycatch. Effect on *Nephrops* selectivity is unknown but likely to be limited.

8.3.5 Grids

Standard (Swedish) sorting grids (bars set 35mm+ apart, often associated with a 70-90mm square mesh panel) have been found to be effective at removing cod but appear to have more limited effect on *Nephrops* selection. Broadly speaking it seems that most grids tend to remove large *Nephrops* as well as fish so they are rarely popular with fishermen.

Grids have been tested in Sweden to reduce the selection range of retained *Nephrops*. Several designs have shown that grids retain *Nephrops* with a smaller selection range[15] than diamond mesh codends (Valdermarsen et al. 1996; Valdemarsen 1997).

Madsen et al. (2008) investigated the possible retention of larger *Nephrops* by increasing the bar distance (to 40 mm) and configuration (larger bar spacing at the bottom of the grid and a hole cut in the top panel). Although some size selection occurred, a total of 20% of marketable catch was lost. In a related study a flexigrid made of rubber with composite bars caught significantly less marketable *Nephrops* than the more conventional rigid sorting grid. A modified grid with wider spacing at the top also resulted in 17% loss of marketable (more than 40mm CL) *Nephrops*.

In France IFREMER has carried out extensive trials on grid bar spacings to facilitate escape of less than 35mm (MLS) *Nephrops*. A flexible grid was fitted in the extension of the trawl and different ranges of bar spacings and shape were tested. Square or cylindrical section bars spaced at 13 to 20 mm resulted in increased L50s (length at which 50% retained). For example, a grid with 20 mm bar spacing introduced into a net with 70mm codend resulted in an increase in L50 from 26.5 mm to 35.8 mm. Cylindrical bars provided better selectivity than the square ones. This work has shown average escape rates of 36% to 57% for undersize *Nephrops* using the grid with very limited commercial losses of approximately 0.1kg of *Nephrops* per trawl. Using a 13 mm bars spacing *Nephrops* discards (less than 28 mm) were reduced by 25 to 35% with no recorded commercial losses (more than 28 mm). However, some subsequent work undertaken by Raveau et al (2012), based on rather limited trials suggested firstly that results were highly variable; and that a gear configuration incorporating a grid had rather limited impact on the catch of small *Nephrops*. Clearly more research is required on this.

Experimental data were collected from a small number of hauls and the distribution of catches in the standard and selective trawls showed a high variability between hauls (Meillat et al., 2011); this was true even in the test of the combined selective device for which there was a higher number of hauls.

In the UK Drewery et al (2011) examined the effect of fitting a *Nephrops* trawl with (i) a flexible grid with 45 mm bar spacing plus large open bottom gaps and (ii) a flexible grid with bars of 45 mm spacing all the way down. Although the gear was effective at reducing bycatch of cod, haddock and whiting, there were no positive selectivity effects for *Nephrops*. Although they found no significant losses of *Nephrops* less than 44 mm (carapace length) from the gear using the grid with the bottom gaps, there were losses in the larger sizes e.g. approximately 20% at 50 mm and 57% at 60 mm. The grid with no large open bottom gaps clogged and functioned poorly.

Montgomerie and Biggs (2012) trialled four different design alterations to a standard *Nephrops* trawl with a view to reducing discards and in particular cod catches. They found that the “Swedish grid” was effective at releasing larger fish but tended to choke, and was associated with safety issues. Plastic grids were less hazardous but released too many *Nephrops*, and were also prone to choking.

In Scotland Seafish has been running flume tank and sea trials on a new grid design aimed at reducing the numbers of discards in the Scottish trawl fishery for *Nephrops*. The main aim of this project is to produce a grid suitable for fitting in the trawls used on Scottish vessels

[15] range encompassing 50% of the catch

and easy to handle on-board. Initial trials with a plastic grid have been promising, reducing cod catches to 1.2% of total catch, although the strength of the grid remains problematic.

The findings in relation to grids appear to be mixed. Some French trials suggest significant opportunities, but most other trials – while often leading to increased (*Nephrops)* species selectivity – demonstrate limited impact on *Nephrops* size profile, coupled with significantly reduced overall catch.

8.3.6 Square mesh panels (SMPs)

Several studies have explored introduction of square mesh panels before the codend or in the codend extension, and the former are now standard requirement for the conservation credits scheme in the UK. Krag et al. (2008, cited in Madssen and Valentinsson 2010) assessed the performance of a 97-mm square-mesh panel installed in gear using a diamond mesh codend in the Kattegat–Skagerrak *Nephrops* fishery. When placed 6–9 m from the codline the panel had no significant effect on the catch of cod, but when placed 3–6 m from the codline catches of cod more than 40 cm were reduced. Unfortunately this introduced a statistically significant (p less than 0.05) 12% loss of legal-sized *Nephrops*.

The studies by IFREMER referred to above also explored use of an SMP in the bottom of the extension. They found escape rates of undersize *Nephrops* were between 20 and 40% for a 70 mm mesh size, but commercial losses were high on small (less than 12 m) boats.

8.3.7 Internal panels and mixed trawl designs

The *Faithlie Panel* and CEFAS Net Grid both use a netting panel to create a physical barrier to whitefish (which escape through a top hole) whilst allowing *Nephrops* through to the codend. The *Flip – Flap trawl* has large mesh sections (topwing, topsheet), a topsheet square mesh panel, internal square mesh flap and a flexible grid to encourage/allow for whitefish escape whist allowing *Nephrops* through to the codend. As far as we are aware these do not affect *Nephrops* selectivity.

Lifting bags.
Although limited studies undertaken in the Irish Sea (Briggs 1981, 1983), showed there to be no significant difference in *Nephrops* size distribution caught by nets with and without a lifting bag, a meta-analysis by ICES (2007) suggested a significant contribution of lifting bag to trawl selectivity, and studies in France by Charuau et al. (1982) suggested that a lifting bag reduces selection range.

A Fishing Industry Science Alliance proposal to examine the selectivity of lifting bags on a *Nephrops* trawl has recently (2014) been accepted for funding and the study will commence in 2015 (Drewery et al 2015).

8.3.8 Coverless trawl

In the UK, Montgomerie and Biggs (2012) found that coverless trawls resulted in little change in catch compositions compared to standard trawls.

8.3.9 Twine thickness

ICES (2007) found no significant effect of twine thickness across studies, but several individual studies did show a significant effect. For example Sala et al. (2006) demonstrated that increased twine thickness of the codend netting resulted in significant decrease in selectivity for all species.

8.3.10 Extension length and codend circumference

Trawls may be extended to facilitate handling, and this might be expected to allow for more escapes. However, since *Nephrops* do not actively attempt to swim through the meshes, little effect might be expected and this is confirmed by some studies (Madsen and Valentinsson 2010)

In Scotland and N Ireland the industry developed several designs which were trialled against standard gear and the Swedish Grid. A boxed codend extension or "Seltra Trawl" (4m box section with 300 mm square mesh; 3m box section with 270 mm diamond mesh) showed the best results in Northern Ireland – but there have been problems with excessive loss of *Nephrops* when introduced into the fishery. Further trials will be undertaken in 2013 with the aim of the whole prawn fleet fishing with more selective gears" (Seafish 2012).

When comparing four different gear modifications, Montgomerie and Biggs (2012) found that a 3-4m boxed extension to the codend, with a large square mesh top panel to allow fish to escape showed the greatest promise, is cheap to construct, and was easy and safe to use. No specific results were found relating to *Nephrops* size selection.

The UK authorities have implemented a management measure to ensure that from 1 October 2010 all vessels fishing for *Nephrops* in Area VIIa (Irish Sea) use a net that incorporates a boxed extension with 70-80mm side and bottom meshes and a 300mm square mesh top panel. This may be used with a 90-120mm square mesh panel (in the top panel of the taper of the trawl (i.e. in front of the box extension) to further increase selectivity.

8.3.11 Short term losses in landings associated with gear changes

Table 8 (source from Madsen and Valentinsson 2010) summarizes the impact on *Nephrops* catch of measures primarily designed to reduce whitefish bycatch.

Table 8: Impact of selectivity trials on Nephrops catch (source: Madsen and Valentinsson 2010)

Selective device	*Nephrops* (%)	Comments
90DMC: baseline	100[b]	Low selectivity of cod
120DMC	86[b]	Only catch of small cod reduced
70SMC	78[d]	Only catch of small cod reduced
120SMC	24[d]	Only relevant when targeting plaice
90DMC + 120SMW	100[e]	No effect
90DMC + SG	70 or 100[f]	Loss of flatfish
90DMC + SFR	88[g]	More research needed
90DMC + 300SB	100[h]	Research on improving flatfish efficiency
90DMC + RTP	81[i]	Only catch of large cod reduced
90DMC + 50% reduced swept area	100[j]	Option worthwhile considering

DMC diamond mesh codend; smc square mesh codend; SMW square mesh window (panel); SG sorting grid; SB sorting box (extension); RTP reduced top panel

It is notable that Increases the codend diamond mesh size has relatively limited impact on *Nephrops* catch, whereas use of a square mesh codend has substantial impact, even when using 70mm.

8.3.12 Meta-analysis of factors contributing to Nephrops selectivity

The most comprehensive information on size selectivity in *Nephrops* trawls was assimilated in an ICES (2007) workshop report. This undertook a meta-analysis of all comparable studies undertaken on net selectivity. They found that at length classes 20, 25, 30, 35, and 40 mm *retention* at a particular length decreased with mesh size, was lower for square mesh than diamond mesh and higher when there was a lifting bag. Perhaps surprisingly, twine thickness was not a significant factor except in one specific data set. *Selection range* was also significantly affected by codend mesh size, shape and catch weight. An increase in mesh size appears to result in wider selection range for both square mesh and diamond mesh codends. However, there appears to be some interaction between catch volume and mesh sizes, with bigger catches resulting in wider selection ranges for larger mesh sizes, but narrower selection ranges for smaller mesh sizes.

More generally however it was notable that selection of *Nephrops* is not consistent. While some trial hauls showed a typical s-shaped or logistic curve of proportion retained against carapace length, others – especially those using diamond mesh codends - show little or no relationship. The proportion of hauls which do not show length-related selection may be as much as 50%. The results of this study are summarized in Table 9. Figures 19 and 20 show derived relationships from the statistical model developed from the data.

Table 9: Data synthesis from ICES 2007 review

Table 1 *Nephrops* selectivity data from ICES FTFB Report 1995/B:2 (All PE material)

Twine Size mm	Mesh Size MS mm	Equiv. Sinle twine size mm*	Open meshes round	50% Retention length L50mm	Selection range SR mm	Selection factor =L50/MS	No of hauls
2.5s	55.2	2.50	218	23.9	9.7	0.43	13
2.5s	60.3	2.50	200	25.7	10	0.43	11
2.5s	70.6	2.50	170	26.9	12.4	0.38	10
4s	71.1	4.00	122	26.1	8.4	0.37	6
4s	72.7	4.00	100	28.4	13.6	0.39	5
4s	74.2	4.00	143	24.5	14.7	0.33	5
4d	81.4	5.66	82	30.3	23.9	0.37	2
4d	83.2	5.66	100	28	18.7	0.34	3
4d	83.5	5.66	118	26.4	25.1	0.32	2
4d	106.8	5.66	85	41.3	15.4	0.39	5
4d	108	5.66	70	43.2	20.5	0.40	4
4d	108	5.66	100	39.7	21.7	0.37	3
2.5s	72.8	3..54	94	37.1	16.2	0.51	10
2.5s	72.9	3..54	94	37.9	16.4	0.52	10

***Equivalent single twine size for double twine is equivalent to twine thickness x √2**

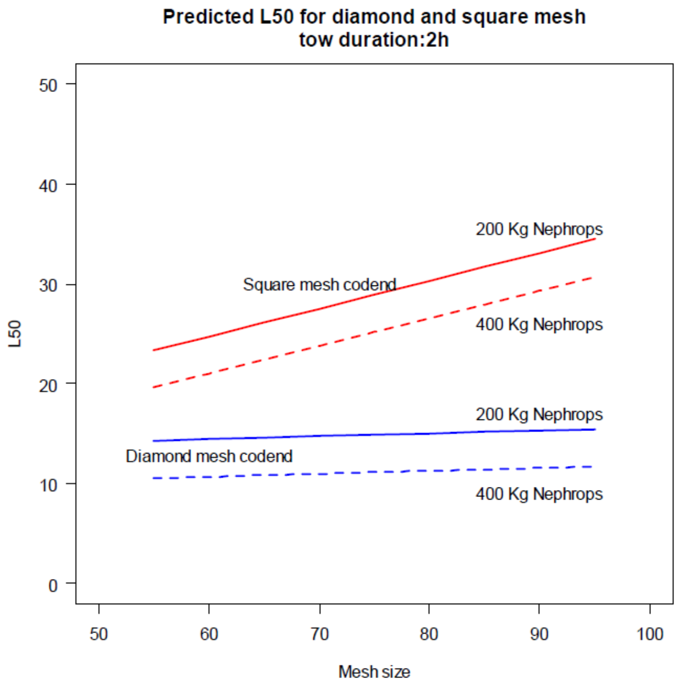

Figure 19: Effect on retention of different square and diamond mesh size (Source ICES 2007)

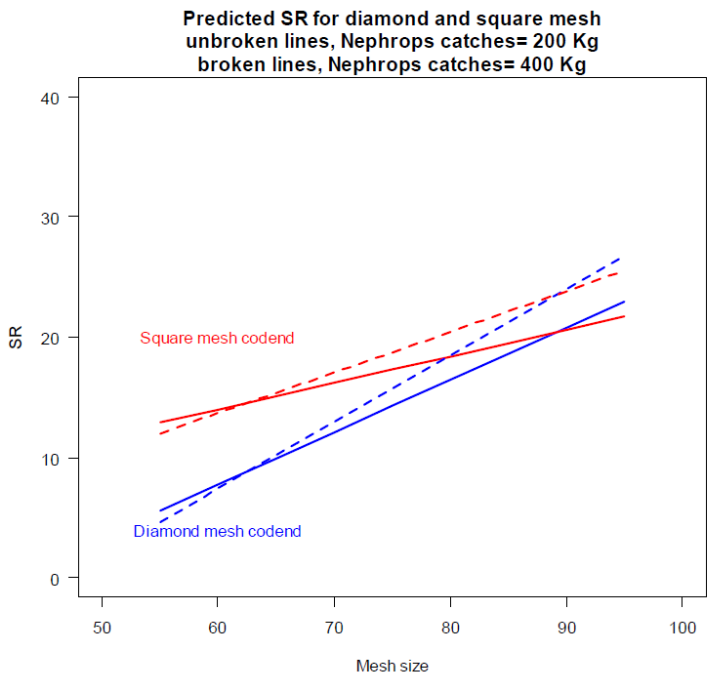

Figure 20: Selection range for different mesh types and sizes (Source: ICES 2007)

ICES (2007) concluded that in the case of the Firth of Forth fishery removal of the lifting bag may give the best outcome for the fleet in terms of overall landings, although biomass benefits considerably more from the use of 70mm square mesh or 120mm diamond mesh codends. In all cases however there are likely to be significant losses of good market sized prawns in the short/medium term.

Potential for trawl gear modification: main findings

- While significant progress has been made in the development of more species selective *Nephrops* trawls in response to the need to reduce whitefish bycatch, little progress has been made in developing gears to reduce the catch of smaller prawns, despite strong incentives in Scandinavia and France as a result of significantly increased MLS. This is mainly because of the shape and behaviour of prawns.
- Although some reduction in catch of small prawns can be achieved, it is usually associated with a similar and substantial loss (up to 40%) of good market sized prawns, and in some cases gear handling problems.
- Nonetheless, there appear to be 3 gear options for reducing the catch of smaller *Nephrops*:
    - Use of square mesh in the codend
    - Use of a separation grid (as developed in France)
    - Removal of lifting bag
- Given the research to date, quantifying the likely impact of any of the above in the case study area will be very uncertain.

8.4 Modifications to *Nephrops* creels to increase landing size

Creels are naturally selective of larger prawns. Firstly, large *Nephrops* spend more time out of their burrows and are more likely to encounter scent plume. Secondly, large prawns will chase away small prawns (Bjordal 1986) from the vicinity of a creel. Thirdly, small prawns are more likely to escape from a creel (or be driven out).

Size selectivity may be further increased through the use of escape hatches. 22mm escape hatches are already used in the Torridon *Nephrops* creel fishery. These should enable smaller *Nephrops* (up to 40mm) and other bycatch species to escape.

Adey (2007) found CPUE of smaller (27-40 mm CL) *Nephrops* of both sexes was lower in 2004-2005, after the introduction of escape gaps in 2003, compared with 2001-2002. CPUE values of medium, large and extra-large animals on the other hand show little variation in catch rate between years (2001, 2002, 2004 and 2005). However, examination of the data (Figure 21) suggests some loss of medium sized prawns. Unfortunately it is difficult to be clear about these results since both catch rates and size profile are in any case highly variable from year to year and location to location.

Some of the skippers from Torridon reported that most of ‘discarding’ happens through the escape gaps whilst the creels are on the seabed leaving only the berried females and heavily encrusted *Nephrops* as discard.

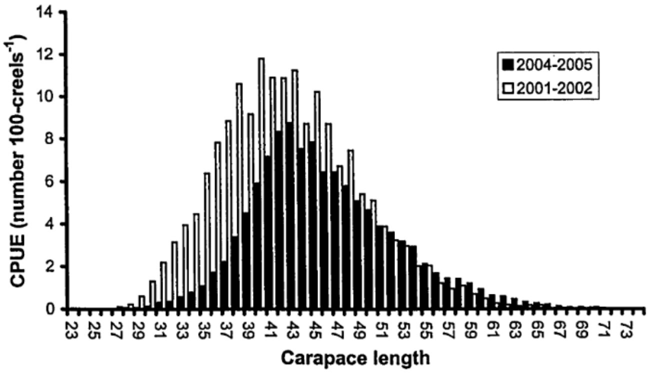

Figure 21: Size profile of creel catch (males) before and after introduction of escape hatches (Source, Adey 2007)

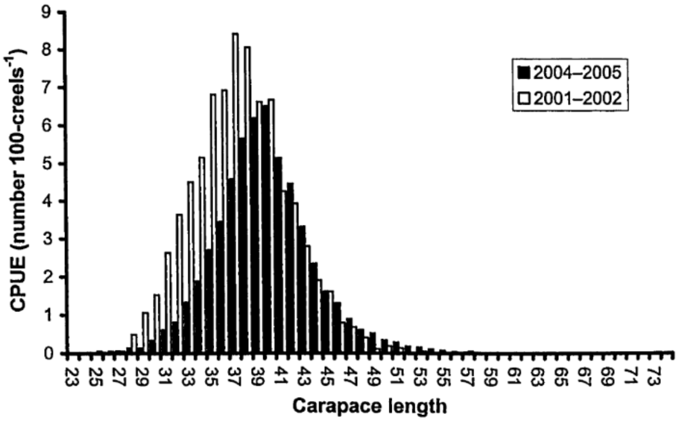

Figure 22: Size profile of creel catch (females) before and after introduction of escape hatches (Source Adey 2007)

Nephrops creel modification to increase size profile of catch: main findings

- Creels are naturally selective of larger prawns and very few prawns (probably less than 5%) are caught of size less than minimum market (live) size of 32mm CL.
- However, some suppliers of live prawn target markets where minimum size for live product is 40mm, and there is some evidence that the use of escape hatches is effective in reducing the catch of *Nephrops* less than 40mm CL, with limited impact on catch of more than 40mm.

8.5 Conclusions- gear

It is clear from all of the above that increasing minimum landing size of *Nephrops* through gear modification will be difficult. Trawls are already relatively selective in so far as animals under 20mm are rarely caught and relatively few less than 25mm are caught for behavioural reasons. Most modifications that result in significantly fewer small *Nephrops* caught also result in significant overall reductions in catch. Only if a MMLS of 30mm or above were feasible or desirable would it make sense to consider gear modification.

8.6 Vessel power

There is anecdotal evidence that vessels with greater horsepower may be less selective. Bova et al (2009) examined this relationship under the Science Industry Partnership scheme in response to a request from Mallaig and NW Fishermens Association. They carried out parallel, simultaneous fishing tows with two vessels, one single rig 177kW and the other a twin rig 375HP. They compared using both 80 and 100 mm codends and 200 mm mesh square mesh panels (SMPs) fitted in the extension. They found that relative catch rates of *Nephrops* did not differ significantly between nets or vessels and there was no evidence of any size selection, nor was there any difference in terms of selectivity of whiting and haddock.

However, this is just one trial, and the comparison is compounded by the use of different gears (twin v single rig).

In practice there seems to be a common view amongst fishermen that smaller boats catch bigger prawns – figures quoted being an average size of 100/kg (=ca 26mm CL) for larger boats and 60-70/kg (=ca 30 CL) for smaller. Whether this is rumour or truth is hard to tell, but it may relate as much to trawling speed and tow duration (both of tend to be greater for larger, more powerful vessels) as much as to vessel power. This is discussed further below.

Finding
There is no clear relationship between vessel power and catch profile, though there may be some effects associated with and duration of trawl (see below).

8.7 Fishing strategy

Changes in fishing strategy and patterns may affect several variables that may in turn be linked to fishing effort, costs or returns.

Any of the following may be considered to be dimensions of fishing strategy, and success exploiting these strategies is a key indicator of fishing skill:

- Travelling to known areas where larger prawns may be found (related e.g. to depth; proximity of closed areas; substrate)
- Travelling to known areas at particular times (tides, seasons, weather) where and when larger prawns may be found
- Trawling for shorter or longer duration and at different speeds
- Leaving pots down for 1, 2 or more days (soak time)
- Retaining or discarding different proportions or sizes of animals

These strategies will have implications in terms of costs (fuel, time, labour) and returns (volume, unit price) and the trade-offs may be complex. Some fishers may make conscious calculated trade-offs; other may operate more instinctively, building up experience of what works best over time. But it is this understanding or experience that differentiates the more successful from the less successful skipper, and that may allow them to exploit market opportunities at reasonable cost. And government information on days at sea and fishing income clearly shows significant differences between similar vessels, which must be largely attributable to these strategies.

8.7.1 Targeting known grounds for larger prawns

It is undoubtedly possible to fish strategically for larger prawns, but in most cases this is likely to be associated with fewer animals, so a trade-off may be involved. Adey, 2007 explored this issue in some detail: “It has been well documented that around Scotland, areas of fine sediment are generally characterised by large *Nephrops* at comparatively low population densities, and areas of coarser sediments are characterised by smaller *Nephrops* at higher densities (Chapman & Bailey, 1987; Tully & Hillis, 1995). Adey confirmed these findings in his own study on the West Coast. It may be that these differences are related to either age or some differences between the sexes, since females are smaller than males. It may also be related to depth: some skippers said that larger prawns are usually taken in deeper water (where sediments are likely to be finer).

Adey (2007) also observed that larger *Nephrops* were caught in the Inner Sound compared with Loch Torridon. However, the LPUE of both the total and medium-sized *Nephrops*, was more consistent, suggesting that any advantage might be relatively limited. He also noted that high levels of fishing effort occurred around the boundaries of the BUTEC no fishing area, and this was associated with relatively high numbers of large animals in the catch.

Several skippers (both trawl and creel) observed a possible positive interaction between trawling and creel fishing with good yields of prawns after the trawlers had been in (although many creelers also emphasised the negative interaction). Adey also remarked that the highest catches of large animals were from a fleet of creels fished in the trawl-only area.

Targeting of areas where larger prawns are to be found may also have a seasonal dimension: many creelers target the larger males on muddy ground in early part of the year, and females on harder ground in the spring as they become more abundant.

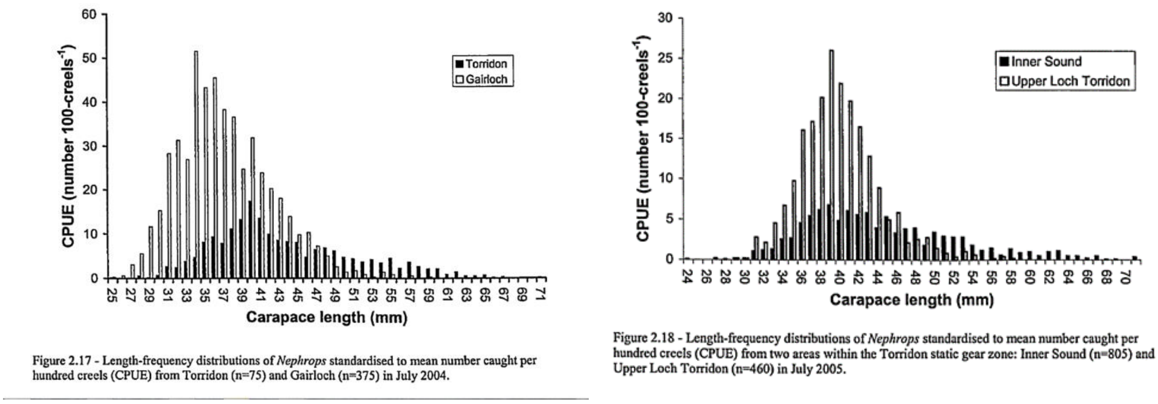

Figure 23: Different size profile of catch in different locations (Source: Adey 2007)

Despite these undoubted opportunities, it has already been noted that most creelers tend to fish within a 15 mile radius of base, suggesting that although it may be worth travelling a bit further to increase the size and/or volume of catch, there are very clear limits to this related mainly to the substantial loss of fishing time and increased fuel costs associated with going further afield. In any case it may not be possible or safe to travel to some of these grounds, depending on degree of shelter, wind direction, weather, tides and sea state.

8.7.2 Exploiting seasonality

There is scientific (Adey 2007), biological, anecdotal and commercial evidence that larger prawns are caught in the first quarter, and catch of smaller prawns peaks in the second quarter.

Adey (2007) recorded a seasonal pattern at all sites in catch composition, with a peak catch of post-moult (soft exoskeletons) males at the beginning of the year, while females are incubating in burrows, followed by a peak in female catch after the mating period in the spring (Figure 24). Numbers of females in the catch then declined until spawning in the autumn, after which they were present in small numbers in the catch.

A possible strategy to increase overall size of catch and reduce catch of small prawns would be to introduce a seasonal closure of the fishery in the second quarter. This would have the added bonus of reducing pressure on the fishery during the mating period, and at a time when price is in any case not high (although there is significant inter-annual variation). However, while average size is much lower at this time of year, quantity is significant and it is often a peak time for trawling activity – especially visiting vessels, for whom size is relatively unimportant.

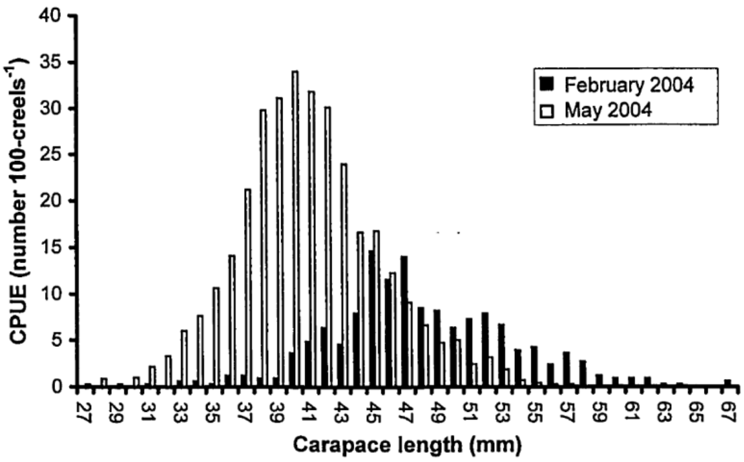

Figure 24: Seasonality of catch profile in the Torridon area (Source: Adey 2007)

8.7.3 Varying soak time of creels

Several skippers suggested that if creels are left down longer, more small *Nephrops* escape, and there is more time for larger ones to enter. However, the advantages decline significantly once the bait is gone, and there may also be territorial effects (i.e. a prawn may be less inclined to enter an occupied creel or may be chased out). Most skippers we talked to used a soak time of 2 days, although a significant number use 1 day only. This is because, for the same number of hauls, a two day soak implies double the number of creels required. In other words there is a trade-off between investment in (and maintenance of) creels, effort and cost getting to the grounds, overall yield, and size profile (value) of the catch associated with varying soak time.

8.7.4 Trawl tow speed and duration

A trawler wishing to land a higher proportion of whole dead and/or live prawns may modify trawl speed and duration to achieve this. Edmonds (2008) for example in a trial to sell more live langoustine from trawls in the Farne deep required skippers to reduce their normal 4hr trawl time to 2hours in order to minimize damage to the *Nephrops* whilst in the net. Several skippers on the West Coast have indicated 2 hr trawl would be required.

Reduced trawl time and speed may have several effects:

- less product in the codend and therefore less crushing (=higher proportion of whole dead v tailed product);
- less time under stress in the codend (higher proportion of good live product);
- better escape of small *Nephrops* and increased average size (enhanced selectivity);
- reduced catch overall (more escapes from a less “clogged” net);

While there is no scientific evidence that trawl speed/time *per se* affects selectivity directly, ICES (2007) found that size selection was directly affected by the *weight of catch in the codend,* and clearly this will be proportional to tow duration. Studies by Briggs (1981, 1983) in the Irish Sea also demonstrated that a full codend reduced the number of escapes through codend meshes and reduced selectivity. This tends to confirm the view that slower, smaller trawls will yield larger better quality prawns. Certainly in our discussions with trawler skippers in the case areas, there was a view that larger boats typically land smaller prawns – typically 100/kg – while smaller boats land significantly larger – perhaps averaging 60-70/kg (Lamont, pers. com)

A change in fishing strategy may also affect handling time, which may in turn reduce effective haul time per day at sea. There are likely to be at least three effects here:

1. A strategy that results in a larger proportion of large prawns should reduce handling time (per unit weight of product).
2. A strategy that increases the proportion of whole dead prawns v tailed prawns should reduce handing (i.e. tailing) time.
3. A strategy that increases the proportion of live tubed prawns is likely to increase handling time

Given that trawlers are designed to catch large volumes of product, the extra sorting and handling associated with live marketing may disrupt the flow of operations and the overall volume taken, and this is likely to outweigh the benefits. According to one of the Skippers we interviewed, the workload associated with modified trawl cycles and the tubing process is nearly doubled. This appears to be confirmed by the relatively low (and reduced) proportion of trawlers that land live prawns. Furthermore the price of trawled live prawns is significantly lower than that for live creeled prawns. This is because 50% of them die before onward sale, and a further significant proportion die in transit or before secondary sales, which not only reduces immediate sales income but may also damage reputation and future earnings.

To date we have been unable to fully quantify these effects, but it seems unlikely that they would be significant compared with the time lost through operating more, shorter hauls.

By way of example, creelers in the Torridon area typically discard prawns under 40mm; while those in Ullapool discard animals under 35mm. This relates to both the nature of the fishery (a higher proportion of smaller prawns are caught in Ullapool) and access to markets that will pay reasonable money for smaller prawns. According to Adey (2007), if Ullapool followed the Torridon discarding practice they would discard 63% of the catch by number.

Creelers also typically discard berried females of all sizes, though adherence to this practice varies from location to location. Some of the skippers from Torridon reported that most of ‘discarding’ happens through the escape gaps whilst the creels are on the seabed leaving only the berried females and heavily encrusted *Nephrops* as discard.

Nephrops Trawlers depend primarily on volume and the tails market, and discarding therefore only relates to the existing MLS of 20mm, and comprises a small part of the catch. In theory, drawing on the catch profile presented in section 9.2, this would amount to less than 1%. It might be expected that anything borderline would be tailed rather than discarded, and that the proportion might be even less. However, discussions with skippers of small trawlers suggests that more are discarded – around 10% by weight and 5% by value.

Case example 1

One limited study has been undertaken specifically to explore the opportunity for landing live trawled langoustines (Edmonds 2008) based on trawlers fishing the Farne deep. Four vessels were engaged for the trial and used a coverless trawl (greatly reducing bycatch of whiting and other whitefish), 90mm codend and a 100mm Square mesh panel. Tows were 2 hours duration compared with normal 4 hours. The trial was conducted just before Christmas when the market for live prawns peaks. Vessels operated normally on some days (all product boxed and sold whole dead) but were fitted with live storage tanks and fished primarily for quality live prawns on other days.

The results in terms of catch, catch composition and value when fishing for live prawns are presented in table C1.

Table C1: catch composition and value of live landings trial (source Edmonds 2008)

Product	weight	%
Grade 1 (less than 15/kg)	95	8%
Grade 2 (16-25/kg)	339	30%
Grade 3 (25-40/kg)	567	50%
dead	128	11%
total	1,129	100%
Average catch/das	**87kg**	
Average value/das	**£550**	
Average survival	**89%**	
Average price/kg	**5.62**	

A comparison was then made with standard landings of iced boxed whole dead prawns from the same vessels on different days during the same period. While these made significantly lower average price (£3.20/kg cf £5.62/kg) landings were substantially higher for the standard dead prawns and overall returns appear to be higher. It is unclear from the paper whether lower landings were related to shorter trawls and longer sorting times, or whether this was simply related to natural variation in catch rates. This study does not therefore cast much light on the economic desirability or otherwise of landing live.

In practice 40-50% of prawns landed on deck from a trawl are already dead. Many studies have shown that a significant proportion of the remainder are likely to die – from gull predation (highly variable, but often serious), from stress, from exposure to lower salinity waters in the upper layers, blindness or other factors. It has been estimated that final mortality of discards varies between 45% and 75% e.g. Guéguen and Charuau (1975) in the bay of Biscay; Wileman et al. (1999), Bergmann et al (2002).

If the landing size increased to 25mm, then around 8% would be discarded, and a further increase to 30mm would require more than 30% discard rate – and its seems unlikely that this would be viable or acceptable as a strategy given the poor survival rate.

8.7.5 Implications of the CFP discards ban for Nephrops trawlers and creelers.

The Common Fisheries Policy (CFP) discards ban (COMMISSION DELEGATED REGULATIONS (EU) Nos. 1393/2014 and 1395/2014) established a discard plan for certain pelagic fisheries in north-western waters and in the North Sea. It came into force on January 1st 2015[16]. By 2019 it will be mandatory for fishermen to land all catch caught - a major challenge for the industry. All catch of fish or shellfish for which there is a TAC quota will count towards the quota limit for that species. This discard ban started with pelagic fisheries and will extend to *Nephrops* and demersal fisheries in January 2016 [17]and across all TAC species by 2019. The velvet crab fishery is not subject to EU TAC regulations and so, as things currently stand, will not be subject to the discard ban.

The Scottish Government, through Marine Scotland Science, has requested that the EU grant a 'high survivability exemption' for *Nephrops* caught in pots, traps and creels. This will free *Nephrops* creel fisherman from any landing obligation and allow them to return discards as at present. The case is thought to be a good one and it is expected that this exemption will be signed off in the autumn of 2015 in time for the enforcement date of January 1st 2016[18].

Trawls targeting *Nephrops* are constructed with smaller meshes (80–90 mm) than trawls used to target whitefish and so consequently, the bycatch of juvenile fish can be substantial (Cappell & MacFadyen 2013). There is no high survivability exemption request submitted for trawled *Nephrops*. Perhaps the most immediate effect on the *Nephrops* trawl fleet will be the issue of "choke" species, where available quota is not sufficient to cover retained catch that would previously have been discarded. For the Irish Sea *Nephrops* fleet in area UK VIIa the choke species is whiting. At average discard rates the fleet would be able to operate for only around 10 fishing days before all the UK VIIa whiting quota was used up (Cappell & MacFadyen (2013). For the North Sea Nephrops trawl fleet the choke species could be hake, with saithe, haddock and whiting also a potential issue. SG are attempting to manage quota transfer to assist vessels (including Nephrops trawlers) to transfer quota in order to reduce the choke effect of unintended catches. A consultation has been launched on the matter, closing 18 August 2015.

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[16] Accessed online 16/07/2015 at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.370.01.0025.01.ENG

[17] Demersel and *Nephrops* landing obligations 2016 SG. Accessed online 16/07/2015 at http://www.gov.scot/Topics/marine/Sea-Fisheries/discards/demersal

[18] Jane McPherson, Seafisheries Division, Marine Scotland Science, Personal communication.

Marine Scotland Science have investigated the possibility of *'de minimis'* [19] exemptions to the discard ban. Models[20] indicate that such exemptions could be applied at fleet level and might keep Scottish fleets fishing at close to current levels, in which case the discards ban would have minimal effect on the industry as a whole. The *Nephrops* trawl fleet discard some 5-10% of catch as legally undersize prawns, usually damaged or dead. The *de minimis* exemption[21], which can be applied at up to 5% of the TAC of all species, may well allow the current discard rate to go substantially unchanged. However, the difference between interpretation of *de minimis* as being a percentage of Member States Total Allowable Catch (TAC) or Member States Total Catch (TC) is critical for both target and choke species; For the North Sea *Nephrops* trawl fleet it has been estimated that if 5% of TC, fishing could continue with 80% of current fishing days; if 5% of TAC, only 47% of current fishing days would be possible (Cappell and Macfadyen, *op cit).*

There is little possibility that retention of currently discarded legally undersized *Nephrops* would increase revenue to the trawl fleet. Such creatures must be kept separately from the main catch and may not be sold for human consumption. *Nephrops* heads could perhaps be used for oil extraction [22] but there may be expense and difficulty associated with collection for processing. Research has identified that there is a use for previously discarded fish as pot bait (Rozarieux 2014), which, if it helped keep costs down, would be a positive benefit to all creel fisherman, including those catching *Nephrops* and velvet crabs.

Discard ban: main findings

- *Nephrops* caught in pots, creels and traps may yet be exempted from the discards ban. SG have filed a 'high survivability' exemption request for creel-caught *Nephrops*. It is expected that this will be agreed autumn 2015. If it is not agreed, creel fisherman will have to comply with the discards ban from January 1st 2016.
- There is no immediate obvious market for trawl-caught *Nephrops* discards. They cannot be used for human consumption. This would create something of a headache if a legally binding increased MLS were to be introduced.
- The white-fish by-catch from *Nephrops* trawlers is likely to limit their days at sea. This may encourage more widespread use of highly selective gear, which will have significant knock on effects in terms of (mainly) the volume and size profile of the catch
- *De-minimis* exceptions might reduce the effects of the legislation.

[19] *De minimis* is a Latin expression meaning "about minimal things". It is used in regulation and law to give exemption where the effect of an action might be minimal or trifling, or in risk assessment to refer to a very minimal risk.
[20] An assessment of the *De Minimis* Exemption in the CFP discarding regulations for Scottish fleets. Simon Mardle for Marine Analytical Unit, Marine Scotland Science. June 2014 Accessed online 15/07/2015 at http://www.gov.scot/Resource/0045/00458153.pdf
[21] In summary, the *de minimis* exemption (Article 15 paragraph 3(c)) allows for discards of up to 5% (7% in years 1and 2; 6% in years 3 and 4) of "total annual catches of all species" where either selectivity is deemed "very difficult" or there are "disproportionate costs of handling unwanted catches". From MSS June 2014 *op cit*.
[22] See Fox, Dr. C. A workshop to address the issues surrounding a discarding ban in the Scottish *Nephrops* fisheries. MASTS 17/06/2015

Fishing strategy: main findings

- Fishermen are able to adjust the size profile and quality of their catch significantly by:
    - Targeting particular fishing grounds
    - Adjusting their effort to exploit seasonal variations in size
- Fishermen can and do readily adjust the size profile of landings through varying discarding practices according to market demand and handling costs
- There is some biological and anecdotal evidence that longer soak times for creels results in larger average size of the catch
- *Nephrops* trawl fishermen can increase the proportion of live and undamaged prawns using slower and/or shorter duration trawls
- There is anecdotal evidence that slower and shorter trawls result in a higher proportion of larger prawns
- The discards ban may encourage adoption of more selective gears in the trawl fishery with possible knock on effects on *Nephrops* catch volume and profile.

9 MARKET OPPORTUNITIES FOR *NEPHROPS*

This section explores the existing distribution and marketing channels from landing to wholesale markets, and establishes benchmark prices, by size and season, to fishermen and to wholesalers. Other significant factors that affect price (related to product characteristics, distribution system or market characteristics) are also explored.

9.1 History

Nephrops were an unrealised resource until the decline of the herring and whitefish in the 1960s and'70s. It was only then that shrimp and whitefish trawlers began to recognize the value of what had previously been by-catch, and dedicated trawling for *Nephrops* became a significant activity. This was primarily for production of "scampi" tails for the booming catering service sector and restaurant/pub meals markets. It was not until the late 1980s that a market opportunity was recognised for high quality live creel caught *Nephrops* for export to continental markets, and this sub-sector then grew rapidly in the '90s and early 2000s.

9.2 Global context and trends

Figure 25 illustrates graphically the rapid increase in *Nephrops* production over recent decades, and the major contribution of the UK and Ireland (roughly 70% in recent years) to that production. However it is notable that while Portugal is the 13th ranked producer by volume the unit value of product is 3 times the European average – and this price differential relates primarily to the larger size of Portuguese prawns, as well as market access. Prices have been as high as Euro 15/kg for trawl caught (fresh) and as high as Euro80/kg for creel caught live product (Leocádio et al 2012).

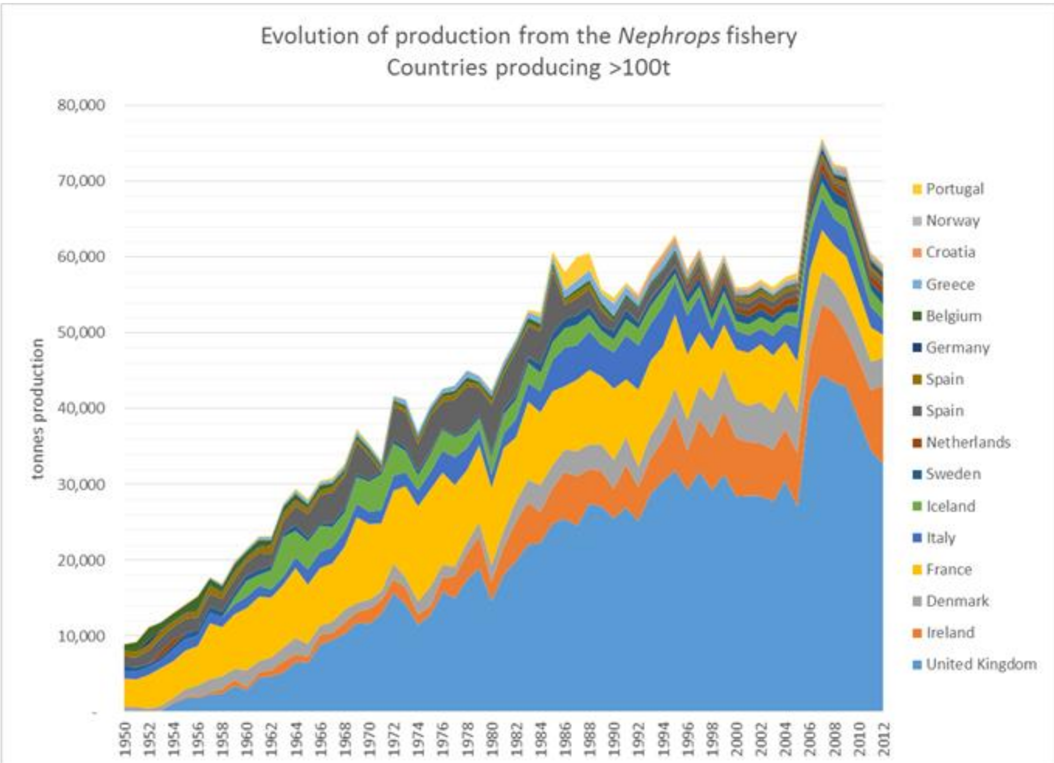

Figure 25: Evolution of the Nephrops Fishery in recent decades. Source: FAO Fishstat

The production graph above, coupled with the various assessments of the *Nephrops* fisheries suggests that production has probably peaked, so that any further increases in value will have to come from size, quality, processing and/or further market development.

9.2.1 UK Exports

A large part of UK production is tailed and processed as “scampi” for the UK market – mainly restaurant and service sectors. The balance is exported, partly as tails and partly as whole fresh, frozen or cooked product. Unfortunately UK export statistics available from HMRC classify *Nephrops* exports as one of two products:

1. Frozen norway lobsters *nephrops norvegicus*, even in shell, incl. lobsters in shell, cooked by steaming or by boiling in water (excl. smoked); and
2. Norway lobsters *nephrops norvegicus*, even in shell, live, fresh, chilled, dried, salted or in brine, incl. lobsters in shell, cooked by steaming or by boiling in water (excl. smoked)

The breakdown of exports by these two classes by month for 2014 is shown in figure 26

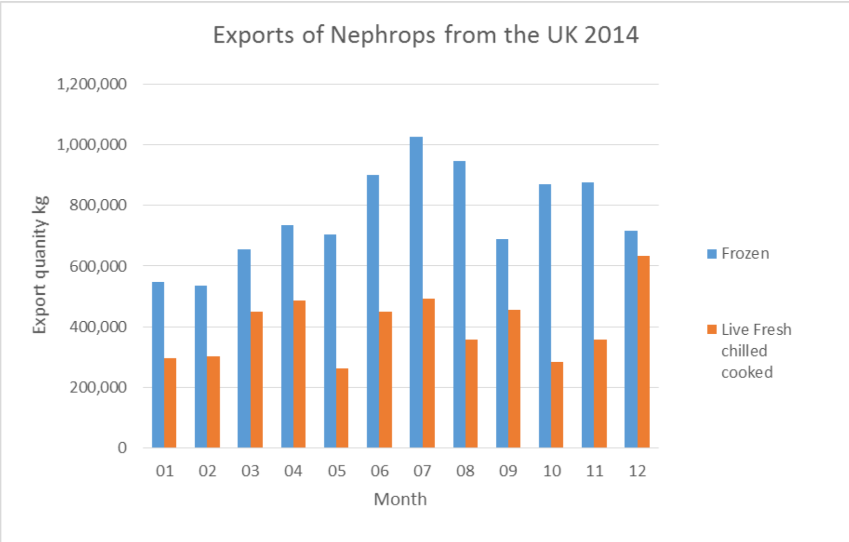

Figure 26: Exports of frozen and fresh chilled or cooked product from the UK 2014

9.3 Products and distribution

9.3.1 Product categories

The main products are:

1. live, whole, minimum size 32mm CL, but for many markets more than 40mm CL
2. fresh (dead) whole, minimum size 32mm CL
3. frozen whole minimum size 32mm CL
4. tails, minimum size = minimum legal size (20mm West Coast, 25mm East coast)

The smaller tails may be combined to make larger pieces of meat in commercial scampi products

9.3.2 Trawl caught prawns

Taking Scotland as a whole (East and West Coast), most trawl caught prawns – around 60% of product - are destined for the processed tail market. Around 35% of product is destined for the fresh wholesale market, which is mainly exported to the continent. The West Coast is slightly different, perhaps reflecting the generally smaller size of trawlers, higher quality of product and emerging market opportunities. At least 75% of landings in the West are of fresh whole product. A very small proportion of trawled prawns are sold live.

Fresh whole and frozen

Fresh whole prawns are usually sold to specialist UK companies or directly to European traders and wholesalers. A significant proportion, especially landed on the East coast, passes through fresh wholesale markets, and may be cooked and or frozen prior to export. Less than 5% of fresh whole product goes to local market (e.g. hotels, restaurants, fishmongers) as fresh whole product.

The proportion of product sold fresh whole and frozen for continental markets from the West Coast has increased significantly in recent years, and traders are actively recruiting trawlers to supply whole fresh product. This may reflect a significant market trend in Europe with increased demand for a cheaper but still high quality product. This perspective is reinforced by the observation that the price of live creel caught prawns was rather low in the early part of this year, perhaps reflecting partial competition with increasing volumes of whole fresh product.

Most of the fresh prawns (between 70 and 90% according to different industry sources) are destined for the French market – mainly supermarket chains in the west of the country, fishmongers and regular restaurants or buffets type restaurants. The balance goes mainly to Spanish and Italian markets.

The Italian market will take smaller fresh prawns (including sizes (31-40) & (41-50) (CL 32mm +).

Spain will not accept berried prawns whereas France does. Spain is also demanding with regard to colour, preferring the bright red prawns

The UK market for the fresh whole prawns is small (probably less than 5%).

Tails

The tails market is primarily in the UK. Industry sources suggest that the majority of product (85- 90%) is purchased by agents and sold on directly to major processors, though a small amount may be sold directly to small local companies. Of the former, 80 to 85% is sold as fresh, frozen, processed and cooked products in the UK, with roughly half of this ending up as breaded “scampi”. A small proportion of tails in various forms are exported mainly to European countries (Italy, France, Switzerland, Germany etc.).

Live

In theory, given the catch profile, around 20% of the catch of small trawlers could be tubed and sold live. In practice very few trawlers land live prawns, though it has been tried by some, and there have been research trials (see case 1,section 9.8.4). Handling prawns for the live market significantly disrupts trawl routines and the price paid for trawled live prawns is significantly lower than that for creeled prawns. This is because they are more prone to mortality in transit and generally of lower quality. For example, in French markets buyers will typically pay 2 euros less/kg (£1.4) for trawled live prawns.

Perhaps of relevance to any development in the trawled live prawn market, the French will take somewhat smaller live prawns than the Spanish.

9.3.3 Creel caught prawns

All creel caught prawns are sold live; the few that die may go to local markets or for family consumption. Most production (probably 90%) is exported to France, Spain and Italy, although a few companies actively target the UK restaurant market. Many suppliers prefer the French over the Spanish market as more reliable and shorter transportation associated with less risk.

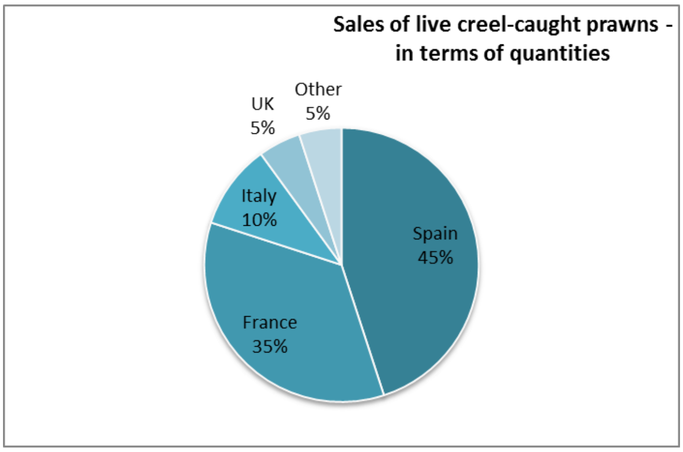

Figure 27: Destination of live caught prawns (commercial sources)

It is perhaps surprising that "other" markets have been so little developed, but this perhaps relates to the exceptional demand in Europe, and the bureaucratic and legal barriers to entry to some markets (such as Russia)

The French market sells live prawns to top restaurants, or in supermarkets / fishmongers for the display.

9.4 Infrastructure and logistics

Over the last two decades there has been significant investment in live shellfish storage infrastructure throughout the West Coast and Outer Hebrides supported by Highlands and Islands Enterprise and European funding.

These facilities are designed for all shellfish species, including prawns, lobster, crabs, scallops and other shellfish – though the main usage is for prawns.

Live storage facilities are often used on a weekly cycle by some companies to keep shellfish prior to distribution by vivier lorries once a week to the Spanish or French markets. There is a Code of Good Practice Guide [23] for handling and storing live crustaceans which provides a good description of the process and also the potential for high mortalities.

9.5 Prices and trends

9.5.1 Live langoustines

The average price for live langoustines in 2014 was £9.3/kg but price is highly dependent on size.

Figure 28, based on commercial data from a significant UK based buyer shows the price seasonality and long term trend for different grades of live langoustine, as paid to fishermen.

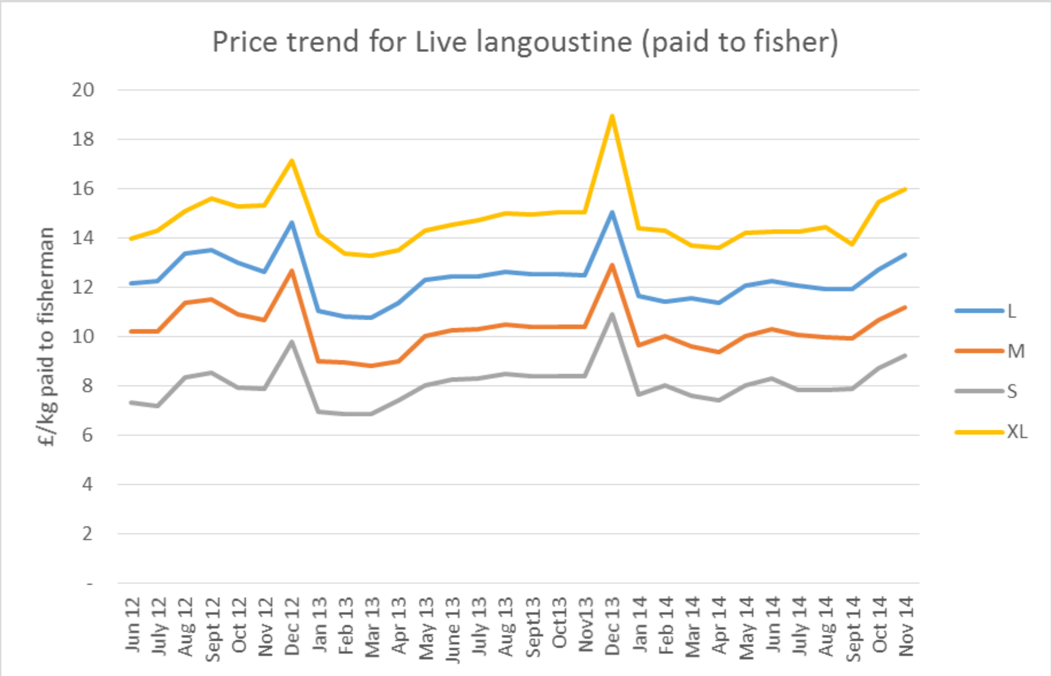

Figure 28: Price seasonality and trends for live langoustine

In terms of carapace length these size grades correspond to, S=35 or[24] 38-40; M = 40-45; L=46-50; XL = more than 50

The key features of this analysis are:

- Long term average price appears relatively stable over recent years, probably reflecting the slowing of expansion in supply, matched by a slowing in demand related to the economic downturn;
- A substantial and consistent price differential of roughly £2 between grades;
- A dip in prices in January/February, followed by steady strengthening from May to November, culminating in a large peak (a £1-2 premium) for the Christmas market

[23] Jacklin, M., and Combes, J., The Good Practice Guide for Handling and Storing Live Crustacea. pp 99-104 and 116- 119. Seafish and Seafood Scotland. http://www.Seafish.org/media/Publications/CrustaceaGPG_0505.pdf Accessed 17/09/2014.

[24] There are variations between buyers

It is worth comparing the above price chart with supply for the same period/trader (Figures 29 and 30)

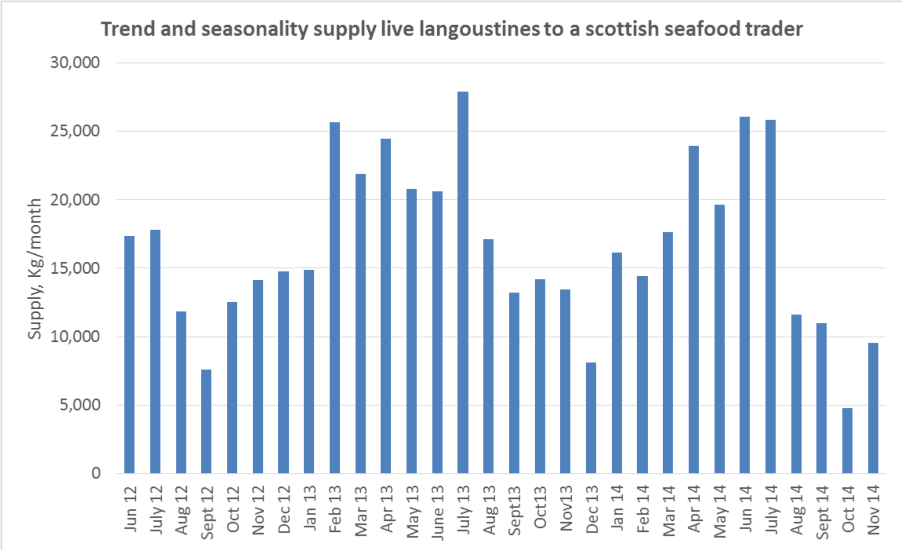

Figure 29: Supply seasonality and trend, live langoustine (all grades)

This illustrates very clearly that supply is driven primarily by weather, day length, and prawn behaviour rather than markets, with the strengthening price in the autumn associated with reduced supply and the peak at Christmas associated with both low supply and high demand. January and February appear to be associated with both low supply and very low demand.

It is also worth looking at supply by size grade to see if this corresponds to the conclusions in the fishery production chapter.

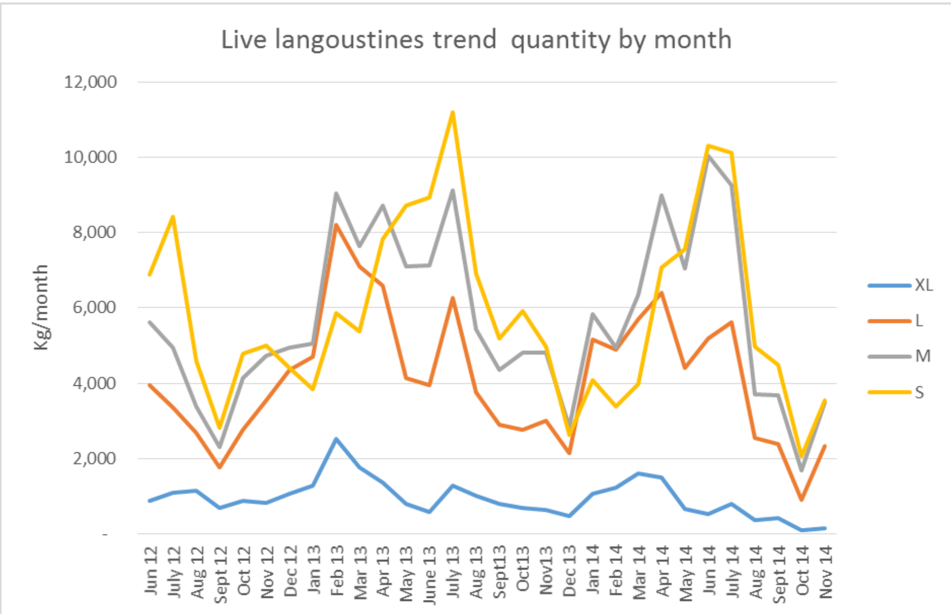

Figure 30: Supply trend for different size grade of live langoustines

Clearly all grades follow the largely weather dependent cycle noted above, but there are some differences, with a peak in medium, large and extra-large in February, and a peak in small animals in June. This corresponds to the biological behaviour of the large post moult males becoming active in the early part of the year and the small females emerging in the spring and summer. In some ways this suits the market, with limited demand in winter (apart from Christmas) other than top class restaurants, where large langoustine will be an attractive feature on the menu.

It is possible to take the supply demand analysis somewhat further to explore price elasticity in response to supply. Figure 31 provides a plot of monthly unit price paid v quantity supplied, and suggests that price is mildly sensitive to supply overall. However this masks the substantial differences in demand supply relationships at different times of year that might be explored with a larger dataset.

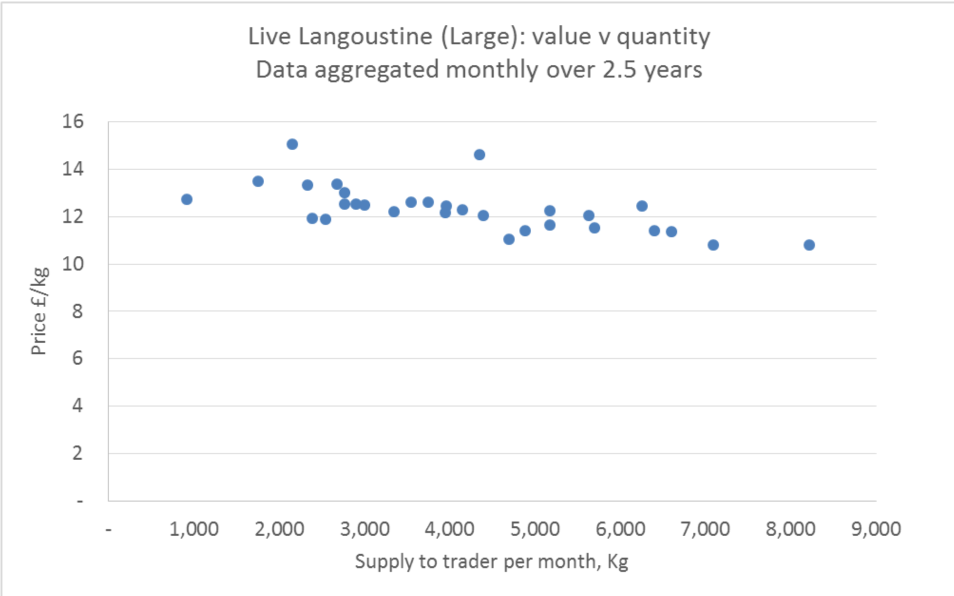

Figure 31: Sensitivity of price to supply

Product ratios

The proportion of different grades of live prawns supplied to a West Coast trader over a 2.5 year period are shown in figure 32.

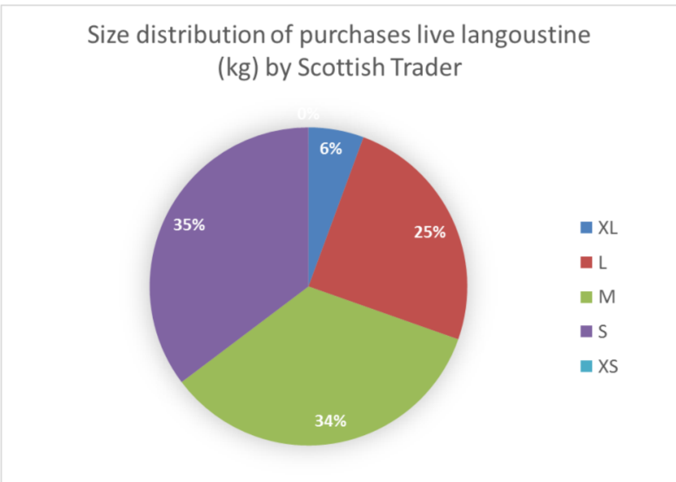

Figure 32: Size distribution of live prawns purchased

These may not be representative of the industry as a whole and is discussed further below.

9.5.2 Fresh langoustines

Price seasonality is less marked for fresh langoustines (Figure 33) than for live product but there is a marked price differential by grade, with the largest prawns worth four times as much per kg as the small grades. This figure also suggests that the Christmas peak may be somewhat less important for the very large grades and very small grades, but still significant for intermediate grades.

The less varied price is perhaps surprising given the large seasonal variation in supply (Figure 34) reflecting the more seasonal nature of trawling for Nephrops on the West Coast. This seasonality is increased by the presence of larger visiting vessels over the summer period. It should also be noted that this data is from just one commercial source, and may not be representative of the general picture and particularly east coast production.

A plot of quantity supplied v price shows no clear relationship, suggesting that price is relatively insensitive to supply and that there is potential for market growth

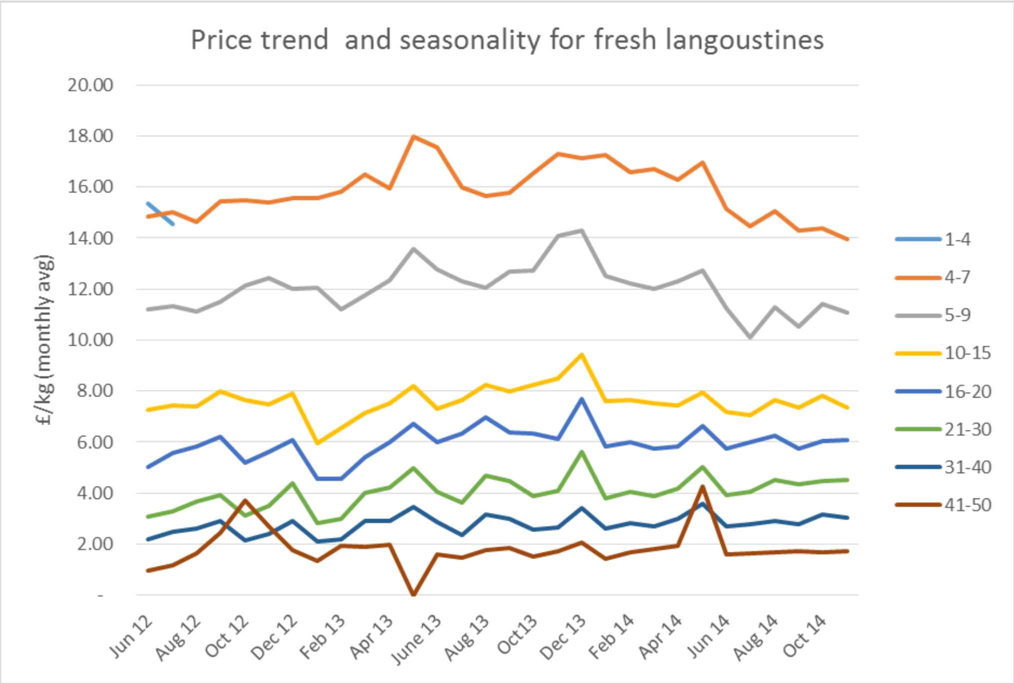

Figure 33: price seasonality and grade differential for fresh langoustines

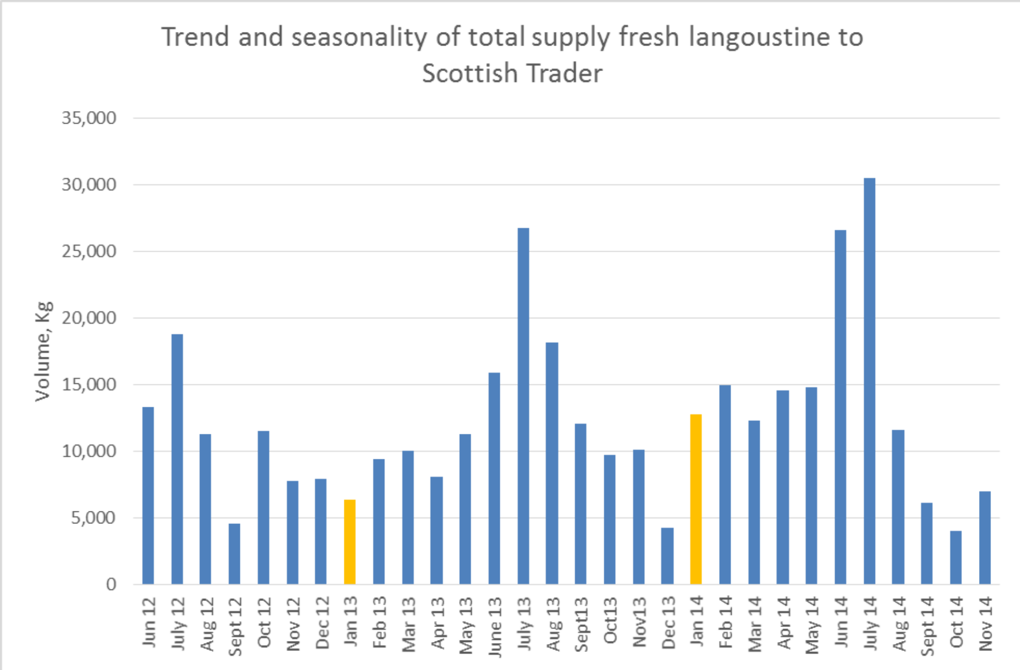

Figure 34: Seasonality of supply to a Scottish Trader

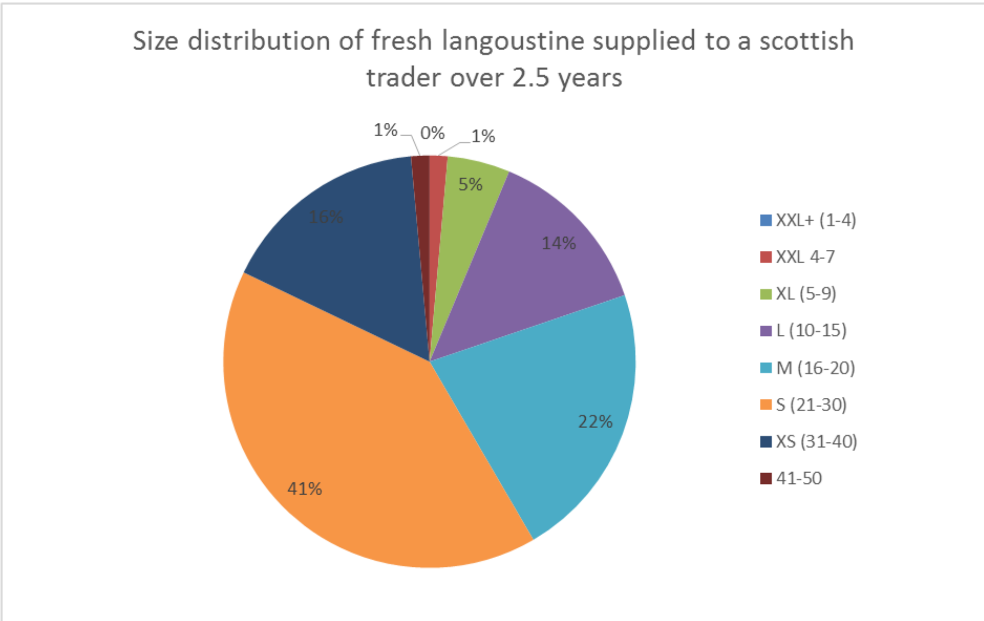

Figure 35: Size distribution of fresh prawns purchased

9.5.3 Tails

The following chart shows prices paid by a trader over a 2.5 year period, showing a very consistent price £5/kg -punctuated by a peak of £6/kg in June 2012. It can only be assumed that there was some short term logistical shortage at that point. Note that these prices would correspond to a live weight equivalent value of roughly 1/3 of this, or £1.7/kg for the prawns as caught, since the tail comprises only around 1/3 of the whole animal.

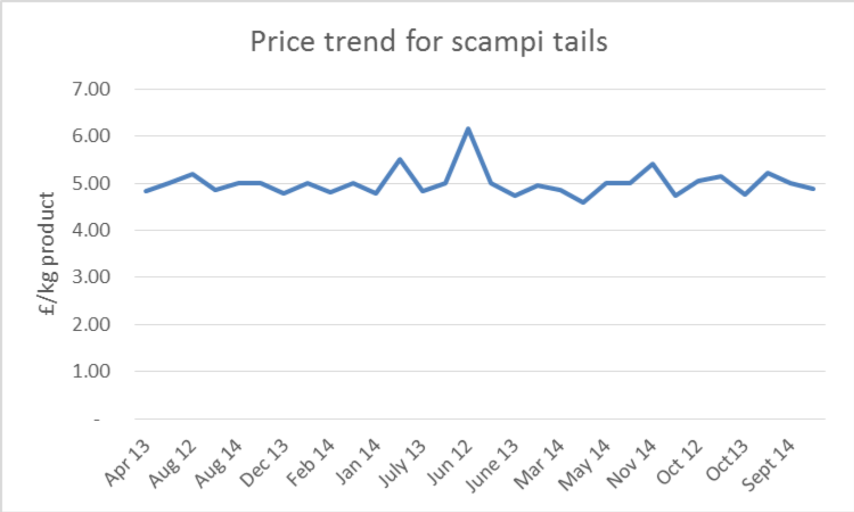

Figure 36: 1st hand purchase price trend for scampi tails

9.6 Benchmark (current) prices by product

Prices vary seasonally, with lowest prices in January/February and highest prices in the autumn and before Christmas. These prices reflect both supply and demand, with limited demand in January/February, increased demand but also increased supply in spring and Summer, reduced supply in the Autumn due to limited light and bad weather, and exceptional demand and limited supply just before Christmas.

Prices also vary according to volume – for both vessels and traders. Higher volume allows for efficiency and predictability and is associated with a significant premium.

Table 10: baseline prices (£/kg) for Nephrops products (source: various)

Count/kg	CL mm	Grade	Live creeled	Live trawled	Fresh whole	Tails
4-7	60 -70	XXL			14-18 (16)	
5-9	54-67	XL	14-18 (15)	12-14	9-14 (11)	
10-15	48-54	L	11-15 (12)	9-11	6-9 (7.5)	£5 (£1.7 live weight equivalent)
16-20	42-47	M	8-12 (10)	5-6	5-7 (6)	
21-30	38-41	S	7-10 (8)	4-5	3-5 (4)	
31-40	34-37	XS			2-3 (3)	
41-50	32-34	XXS			2-3 (2)	
more than 50	less than 32	Tails				

Note that in general

- The high end of the price range corresponds to Christmas prices;
- Higher prices are paid for larger volumes

9.7 Future opportunities

9.7.1 Live trawled prawns

The price for live trawled prawns appears to be rather lower than it might be given the smaller price differential (£1.40/kg) in French markets. However, this probably reflects the increased risks between UK suppliers and foreign markets, since higher in transit mortality is likely. This price differential, coupled with the substantial time cost to trawler fishermen, has been a significant disincentive to the development of this market segment. One way round this may be for smaller trawlers (that typically have higher quality product) to land their boxed product in the normal way (some of which is live) and for traders with holding facilities to select the best live prawns and store them in a holding facility for 2-3 days until recovered (or dead) followed by marketing in the normal way. Fishers would be given a slightly enhanced price depending on quality, refined through experience. This would also provide a small incentive to fishers to improve handling to maximise quality and survival.

However, given the relatively high volumes caught be trawlers, the impact on the market price could be substantial, undermining the viability of the option itself as well as the viability of the existing creel fleet.

However, prices for live and whole fresh langoustine rise steadily through the autumn and peak at Christmas time. There may be an opportunity for trawlers to land more live prawns at this time to meet market demand. This is in any case a period when the length of trawls and volume is severely curtailed by weather and day length, the relative benefits of focusing on a smaller quantity of more valuable product may make good sense. And seasonal entry into this market would have a lesser impact on both price and the viability of the creel fleet.

There is also a good market locally for live trawled prawns, and vessels can earn between £5 and £10/kg more than the normal traders price, if they can find a reasonably convenient outlet such as a restaurant or local specialist distributor.

9.7.2 Fresh whole prawns

There are some signals that the demand for whole fresh prawns and whole frozen prawns may be rising as a cheaper partial substitute for live prawns in the high end supermarket and mid-level restaurant market in continental markets and specifically in France. This could increase the relative value of larger high quality prawns to trawlers, and incentivise shorter trawls and improved handling. It might also reduce the costs of and resistance to an increased MMLS.

9.7.3 Emerging markets

In recent years a small amount of live product has been exported to Portugal, Belgium and (prior to sanctions) Russia. There may be potential to expand sales in all these markets, and especially in Russia where historically they have accepted small prawns. Sales are now also increasing to the Far East and SE Asia, including Singapore, Dubai & Hong Kong.

9.7.4 Local Markets

There is already significant local supply to major restaurants in the Skye-SW Ross case study area and there is an increasing trend in sourcing local seafood. This demand is already partially met through specialist local distributors and/or direct initiative of individual vessel owners.

It is likely that the local markets could be further developed through direct marketing to local B&Bs and self-catering. The former increasingly offer lunches and dinners on a flexible basis, and serving local seafood could rapidly enhance reputation in a competitive market. People in self-catering will often treat themselves to something special, so again there are opportunities here for local specialist distributors or individual vessel owners.

9.7.5 National markets

In the central belt there appears to be limited potential. Top end restaurants are only interested in whole prawns, usually live, and are already catered for by existing suppliers. A few other restaurants are interested in prawns – probably fresh, but our survey revealed rather limited interest or opportunity beyond what is already being done.

It seems rather odd than fresh frozen *Nephrops* tails (unbreaded) have not entered the frozen “king prawn” market in the UK, which is robust and reasonably high value. This deserves further exploration.

Market opportunities – main findings

- There may be an opportunity for trawlers to meet some of the excess demand for live prawns in the Autumn and at Christmas time
- The market for whole fresh trawled prawns appears to have strengthened this year relative to that of live prawns, and this may reflect a longer term trend.
- There are undoubtedly emerging market opportunities in east and SE Asia where prawns and novelty are both highly prized. It seems that the strength of the European market has served as a disincentive to market diversification in the past.
- There are modest but probably increasing opportunities for local marketing initiatives in the more touristic areas. These are being taken up, and there are a variety of initiatives – including direct sales by skippers, and the emergence of more local seafood distribution companies.
- Overall, most of these opportunities favour a larger animal, and the rationale for an increased MMLS is thereby strengthened. However, to date this is not reflected in any increased price differential.

10 SHORT TERM COSTS AND RETURNS ASSOCIATED WITH ALTERNATIVE STRATEGIES AND SCENARIOS

10.1 Baseline

Baseline costs and returns have been estimated using the Seafish economic performance database, modified as appropriate to reflect the particular characteristics of the local fleet and information from local skippers. This has proven surprisingly challenging. Many of the costs in the Seafish economic performance database are estimated on the basis of a standard proportion of fishing income, derived from an average for a sub sector (e.g. less than 10m pots and creels). In reality costs/unit income will vary with productivity (catch per unit effort) and the value of the product, and the focus of this study is primarily concerned with how costs and returns respond to changes in productivity and value associated with any change in MMLS.

A further significant problem relates to the estimation of capital related costs (depreciation, interest/finance) which – while there are standard protocols – are nonetheless estimated (or at least perceived) differently by different types of enterprise. Furthermore, these costs are not independent of gear and maintenance costs, since real depreciation will be much lower when more is spent on gear and maintenance. In practice depreciation is relatively low for most vessels, partly because of their age (typically 20-30 years) and partly because of regular gear replacements. Financing structures are likely to have a significant effect on the way in which fishermen respond to any management changes, and deserve more detailed research.

For the purposes of this analysis we have therefore had to make significant assumptions, based on information in the Seafish database, coupled with information on the nature of the local fleet, and typical production parameters, derived from a wide variety of industry and research sources. We have assumed that many costs are directly proportional to days at sea (rather than income as assumed in the Seafish database) – allowing us to explore the impact on costs and returns of any changes in productivity or market value. Other costs are taken as fixed irrespective of days at sea, landings or income. Nonetheless we have retained the main cost categories as used in the Seafish economic performance database:

- Capital (depreciation, interest, dividends)
- Insurance
- Fuel
- Labour
- Maintenance (repairs, gear, hire, others)
- Bait
- Boxes and ice
- Commission, harbour dues, subscriptions and levies (selling costs)
- Other fishing expenses (shore labour (very limited); provisions; crew travel; quota leasing, and days purchased)

A full set of assumptions, parameters, and input values for 5 baseline enterprise models representative of the case study area are presented in Annex 3.

10.2 MMLS Scenarios

We explore the impact of two main MMLS scenarios on costs and returns of both trawl and creel fleet.

The scenarios are:

Scenario 1: Introduction of a scheme to reduce catch of smaller prawns (less than 30mm) for the whole fishery. This would only affect the trawl fleet since the market for live prawns (creelers) will not accept animals less than 32mm CL.

Scenario 2: Introduction of MMLS of 40mm CL for the creel fleet within creel only zones

Scenario 1
Given the possible implication and uncertainty over discard rules, it is highly unlikely that anyone would agree to a compulsory increased MLS regulation (to say 25 or 30mm); if implemented rigorously it would effectively remove small *Nephrops* from the tails market and turn them into “not for human consumption”. This would be perverse unless it had major stock benefits, and stimulated rapid changes in gear size selectivity – which as we have noted elsewhere in this report will be difficult.

We therefore assume instead some form of regionally agreed best practice coupled with the introduction of gear modifications that would reduce the catch of smaller animals. It may be that some form of French grid would meet this requirement as discussed in section 8.3, although we have neither clear data for this nor experience of its use in Scotland. This might be coupled with, for example agreement on length and speed of tow (assuming that a shorter slower tow is both more selective and effective at increasing the proportion of whole fresh product). Furthermore, gear innovation and shorter and/or slower tows may reduce whitefish bycatch and help meet the demands of the discard ban. Fishers may also travel to different grounds known for the size of their prawns (though this is unlikely to last for obvious reasons).

Scenario 2
For Scenario 2 it is assumed that the protocols already operating in some areas, notably escape hatches to allow animals up to 40mm to escape, and live discard of any smaller animals caught, are extended more widely to all existing creel only areas, and that ultimately creel only areas are extended more widely (e.g. as in 3 mile mobile gear exclusive zone). It is also assumed that soak time of creels is 2 days, based on the assumption that the size profile of prawns is increased with soak time as discussed in section 8.

10.3 Impact of MMLS scenarios on costs and returns

In practice the fishing operating costs associated with any change in MMLS are likely to be relatively insignificant compared with the changes in return (associated with increased unit value and/or reduced volume), but we briefly review them below and propose some slight changes to operating cost parameter values associated with different strategies and scenarios.

A full set of assumptions related to the impacts of these scenarios is presented in Annex 3.

10.3.1 Impact of scenario 1 on trawling costs

Clearly there is limited scientific evidence to support any particular assumptions, but the following are presented for illustrative purposes. Furthermore they serve as a basis for sensitivity analysis to explore what level and kind of change might be associated with acceptable shorter term costs.

Intangible capital. It is arguable that any measure to increase the sustainability of the fishery will increase the license and/or quota value

Capital depreciation. The direct costs of introducing modified trawl gear (e.g. square mesh codend; separator grid; removal of lifting bag) is likely to be insignificant if phased in over a period of time, since most nets are in any case replaced every two years or so, and may be modified in any case.

Maintenance. Under this scenario, gear is being set and hauled more regularly (effectively twice as often/hr of trawling) with possible additional impacts on wear and tear, although the weight of the catch will be less for each haul. Overall we expect wear and tear on gear and nets to be somewhat higher.

Labour. Labour is calculated as a function of days at sea and number of crew. It is assumed that this will not change under the scenario. However, there may be a slight reduction in labour associated with reduced time spent sorting a smaller number of larger prawns. Equally there may be a requirement for improved handling practice to maintain a higher proportion of quality whole or live prawns. Either way this will affect the number of tows achieved in a day rather than labour costs per se, and is accounted for accordingly.

Boxes and ice etc. Assuming a small reduction in the volume of the catch, there should be a small saving on boxes and ice. However, since a smaller proportion will be tailed, and since whole prawns require more space, this is likely to cancel out. There may be additional investment costs, of perhaps £1000, associated with live storage, if this option is taken up.

Other fishing expenses (commission, provisions, shore labour, quota leasing, days purchased, crew travel). There may be a modest decrease in shore labour associated with lower volume higher value product. This is unlikely to comprise more than a 5% reduction for this category

10.3.2 Impact of scenario1 on production parameters

Length of tow. We assume this parameter is halved (i.e. typical tow reduced from 4 to 2 hours to ensure a higher quality catch and higher sales of whole fresh prawns)

Tows per day. Since the length of tow is halved the number of tows per day might be doubled. However, the time hauling (30minutes/haul) and setting gear (15 minutes/haul) is also doubled, meaning the number of tows possible is reduced. Overall there will be a significant reduction in towing time/das. We have developed a subroutine relating to tow length that allows for the exploration of a range of possible responses and impacts at different times of year.

Fuel per das. There may be a slight positive impact on fuel use/das. Using a more selective gear and shorter tows should lead to a lower volume of higher quality catch. This might reduce towing resistance marginally, and reduce fuel costs. Equally there will be more time spent hauling per hour of trawling, and this will effectively increase fuel costs. Overall we anticipate this as neutral.

Fuel/das might also be increased if trawlers travel further to seek grounds with larger prawns but any figures here would be purely arbitrary and possibly misleading.

10.3.3 Impact of Scenario 1 on returns

The value of the catch – in terms of £/kg landed – depends on the size profile and fate of the catch as discussed in section 8 and presented in Annex 2, and the value of different product categories as discussed in section 9. Based on the review in section 8, we have made assumptions about the possible impact of scenario 1 on both catch profile and quantity. It is assumed that introduction of scenario 1 management regime will result in an increased overall size profile, coupled with reduced CPUE, especially for the smaller animals. Given the substantial uncertainties associated with these assumptions we offer three subsidiary scenarios – *optimistic* (assuming that a significant gear innovation (perhaps the French grid) allows for an increased size profile with only a small reduction in total CPUE; *most likely* (assuming that an increased size profile is associated with a modest reduction in total CPUE); and *pessimistic*, corresponding to a significant reduction in catch associated with increased size profile – as found in many trials to date. The actual factors used for adjusting CPUE for the different size categories are given in Table 11 . It should be emphasised that – given the uncertainties and variations described in section 8 - these are highly speculative.

Table 11: Adjustment factors to CPUE by product size under subsidiary impact scenarios

carapace mm	Most likely	Optimistic	Pessimistic
60 -70	0.85	0.9	0.8
54-67	0.85	0.9	0.8
48-54	0.75	0.9	0.6
42-47	0.75	0.9	0.6
38-41	0.7	0.8	0.6
34-37	0.65	0.8	0.5
32-34	0.6	0.7	0.5
25-32	0.45	0.6	0.5
20-25	0.45	0.4	0.5
<20	0.45	0.4	0.5

It is assumed that there would be no impacts on the creel fleet under this scenario

10.3.4 Impact of Scenario 2 on creel fleet costs

Capital depreciation. Fitting escape hatches will affect the capital cost of creels. The hatches themselves cost 30 - 50p each. Fitting is likely to take 5 to 10 minutes or around 50p. Overall costs then are likely to be of the order of £0.5 to £1/creel. For vessels with 500+ creels this therefore represent a modest one off investment. It should be noted that some creel fishermen are already implementing this measure.

A doubling of soak time effectively means doubling the number of creels required to maintain the same rate of creel hauling over a fixed period. By way of example, there is a fine period of weather in June and good catches to be had. Any commercial creeler would wish to maximise the fishing effort during this period, and would therefore wish to be hauling creels every day. Let us assume he owns the maximum number of creels that can be hauled and set in a day. All else being equal, if he were to double soak time he would halve the total number of hauls during this period. While catch (or return) per creel haul may be increased, his fishing effort or opportunity is effectively halved during this fishing period. For this reason, skippers who wish to increase soak time also wish to increase the number of creels in proportion, so that fishing opportunity (or effort during favourable fishing times) can be maintained. This is therefore a substantial investment given the cost of creels at between £25 and £50/pc, meaning that a vessel hauling 500 creels/day with a 1 day soak would require an additional 500 creels (£15,000 to £25,000) to maintain the same number of hauls during a favourable fishing period. Assuming a 7 year creel life this would amount to additional annual depreciation of around £3,000/yr, plus some additional maintenance costs of perhaps £1000/yr. These costs are factored into the model via the soak time parameter.

Fuel/das. The costs of this strategy are dependent upon the increased steaming time to the relevant grounds and this will depend on the base of the fishing vessel and the spatial and seasonal distribution of fishing grounds with larger prawns. It is beyond the scope of this project to model this accurately; but it is possible to make assumptions and/or explore trade-offs, such as how far it would be worth travelling to achieve an improved product profile. The basic costs and returns models will allow for this.

However, it is realistic to assume that most fishermen are already implementing this strategy as far as is economically or practically feasible.

10.3.5 Effect of scenario 2 on production parameters

Creel soak time. We assume a soak time of 1.5 days for the baseline and 2 days for scenario 2.

Pots hauled/day. We anticipate no change, since this is a function of technology and crew.

Catch per 100 pots hauled. It is assumed that total catch would increase modestly with soak time. Equally, the use of escape hatches and discard of animals under 40mm will reduce catch/landings rate. In the absence of any reliable data on these trade-offs, we have assumed that they cancel out – in other words the total weight of the catch landed per haul is maintained, although the size and value of the product is increased.

10.3.6 Effect of scenario 2 on catch profile and returns

We assume that the CPUE increases by 10%; but that this is balanced by the increased rate of discard (escape hatches are not 100% effective). This means that the total effective CPUE of landed product will remain largely similar, but it will be comprised only of animals larger than 40mm.

10.4 Results

The full set of model outputs are presented in Annex 3. These are summarized, in terms of return on labour (£/crew/das) in table 12.

Table 12: Summary of economic performance (return on labour) for baseline and scenarios

	Return on labour (£/day) for 2 scenarios (4 sub-scenarios				
Fishing enterprise type	<10m creel (<100das)	<10m creel >100 das	<9.9m trawl	12m trawl	14.5m trawl/visitor
Baseline	28	252	91	162	257
S1 (opt.)			-9	43	148
S1 (ML)			-64	-26	84
S1 (pess.)			-121	-89	-14
S2	18	275			

Findings: short term financial impact on fishing enterprises

- Any increase in MMLS is likely to have immediate significant negative effects on costs and returns to the trawl fleet, with the reduced volume of the catch outweighing the modest improvement in the value of the product.
- This does not take into account the potential for additional income for live prawns, if vessels chose to develop this market. However, as things stand it is highly unlikely that this would compensate for the loss of smaller prawns, and the impacts on total trawl time of the reduced tow times that would be required.
- For the creel fishery the impact of scenario 2 is also negative, though much would depend on the demand for live prawns of 32-40mm CL. While some traders/market outlets readily accept these prawns especially at peak season, this is not the case for all traders/markets, and for this reason some creelers already apply scenario 2 voluntarily. As such these costs would only apply to that part of the fleet that currently supplies somewhat less demanding traders/markets.
- This does not take into account possible future benefit from a) allowing smaller animals to grow or b) benefits that might arise from increased levels of reproduction. The former is dealt with in the next section.

11 POTENTIAL FOR STOCK AND YIELD BENEFITS

While the previous section dealt with immediate short (1-2 year) term impacts on returns to fishermen arising from shifts in gear or fishing practice designed to reduce landings of smaller prawns, the following explores the possible medium term (2yrs +) benefits arising from “letting the prawns grow” as might be expected to result from these changes in fishing practice and landings profile. The following relates primarily to the North Minch *Nephrops* fishery, and to prawns primarily landed through trading networks from Skye and the NW. However we have also undertaken some preliminary analysis relating to velvet crab.

11.1 Methodology

A yield-per-recruit approach coupled with decision theory has been used to estimate optimal size of capture in the two fisheries, and the possible impact of the scenarios discussed above.

This approach assumes that an animal should be retained if the expected benefit from retaining it exceeds the expected benefit from discarding or avoiding it but recapturing it later. The benefit from releasing or avoiding the capture of the animal is the sum over time of the probability of its capture at some future time multiplied by the value of the animal at that time of capture. The analysis takes into account the selectivity of the gear (i.e. the relative probability of capture of different sized animals), discard mortality, growth rate, natural mortality by size/age class, and the relative market value of different sized animals. Most of the model parameters have been taken from the ICES WGCSE (2014) stock assessment for *Nephrops* functional unit 11. More details of the analysis are presented in Annex 4.

11.2 Main findings

Since male *Nephrops* grow to a larger size than females, release of smaller males tends to generate higher benefits that release of similar sized females. The size class with the highest biomass in an unfished population (Lopt) is 44.5mm CL for males and 28mm CL for females. However, the value of the different sized animals should also be taken into account. Assuming a harvest ratio of 14%, and taking into account growth and survival, the relative value of different sizes of *Nephrops* is shown in Figure 37. The implications for MMLS at different rates of fishing mortality are shown in Figure 38.

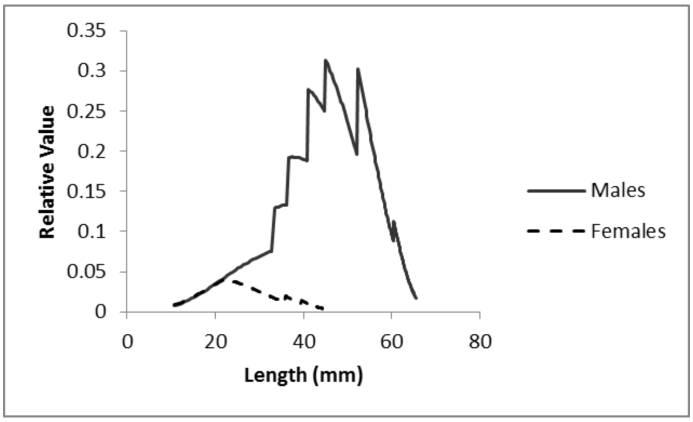

Figure 37: Relative value for males and females as a function of length

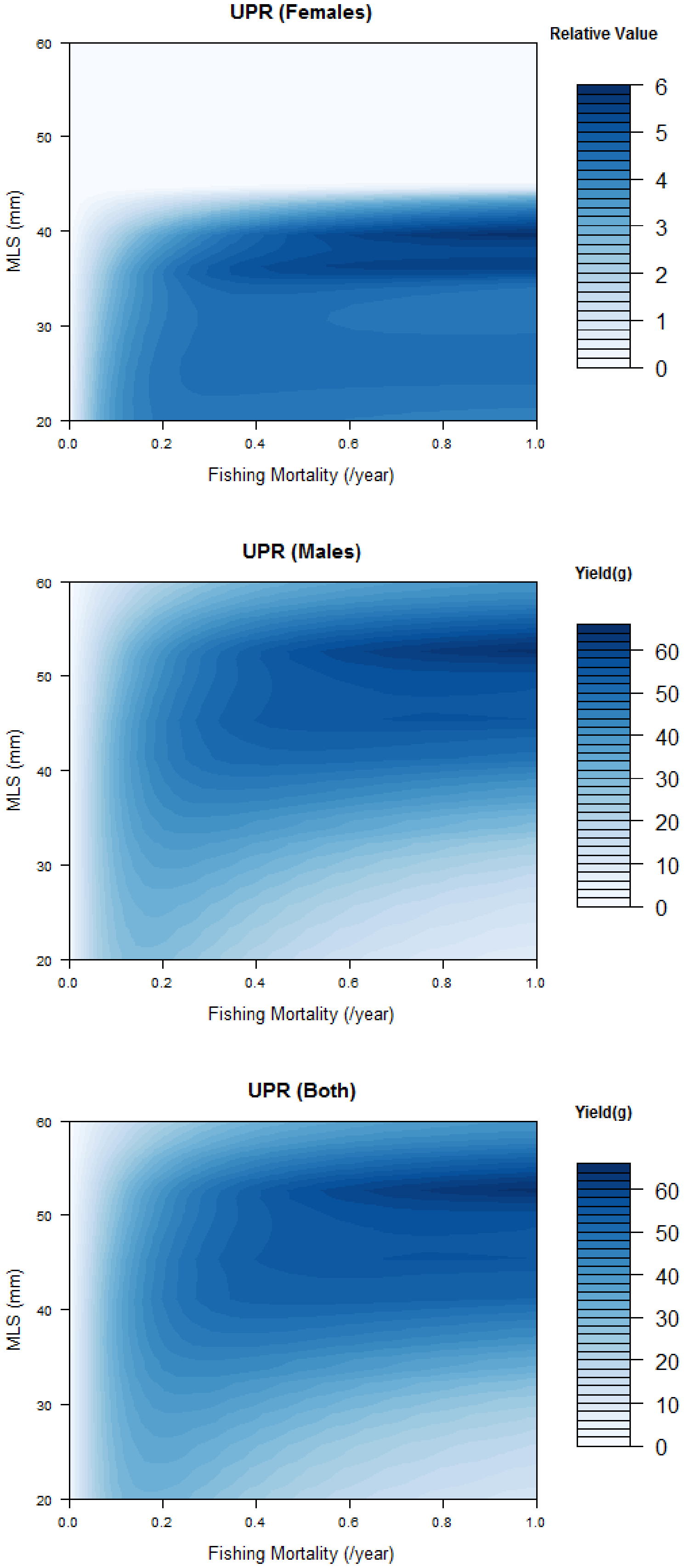

*Figure 38: Utility (price*weight) per recruit for Nephrops assuming knife-edge selectivity.*

11.3 Decision analysis

The decision theory approach provides a clearer output in respect of making the decision, where to place the MMLS.A decision analysis can be used to combine various factors including selectivity in a more realistic way than can be achieved through per-recruit approaches, and in particular can account for uncertainty.

Selectivity and mortality are set so that the models are consistent with observed size composition of discards and landings and the stock assessment. These include:

- Growth for males and females, consistent with per-recruit approaches as above;
- Price changes with size;
- Selectivity models for creels and otter trawl

However, the model used here does not include growth variability, errors in the selectivity model or gear interactions (trawl and creels are assumed to be fishing separate stocks). These factors could be considered in future, but may not be the greatest source of error in these models. Most importantly, the assessment used here does not include *Nephrops* stock dynamics such as stock recruitment effects and conservation constraints (e.g. current application of FMSY or use of the survey data). The implication is that the exploitation rate is not considered directly, but input as a fixed parameter.

A higher exploitation rate will generally increase the chance of capture, making higher MLS more beneficial. Significant changes to the current exploitation rate (e.g. increased number of traps, vessels or TAC) could change the value of different MLS. Perhaps a more important consideration is the conservation objective to maintain spawning stock at sufficiently high levels that recruitment would not be impaired. Higher MLS will generally help with this objective, a consideration which may override any yield-per-recruit measures considered in this analysis.

The overall capture probability has been constrained to the exploitation rate set in the stock assessment, so the overall mortality is scaled to the overall capture probability of 14%.

The optimum MMLS size is the point where the expected benefits for not retaining a *Nephrops* is zero. For creels, where discard mortality is considered negligible, the optimum size for retaining females is around 25mm, and for males is around 34mm CL (Figure 39). This corresponds to retaining males as soon as they enter the 31-40 count per kilo size category. For trawls including discard mortality, suggests that the optimum size for retention is slightly lower than the current MLS (Figure 40). If discard mortality is assumed to be zero, there is some benefit from avoiding capture of males to above 25mm (Figure 41). Technical changes to gear and improved handling would be required to achieve sufficiently low discard mortality to make increased discarding beneficial.

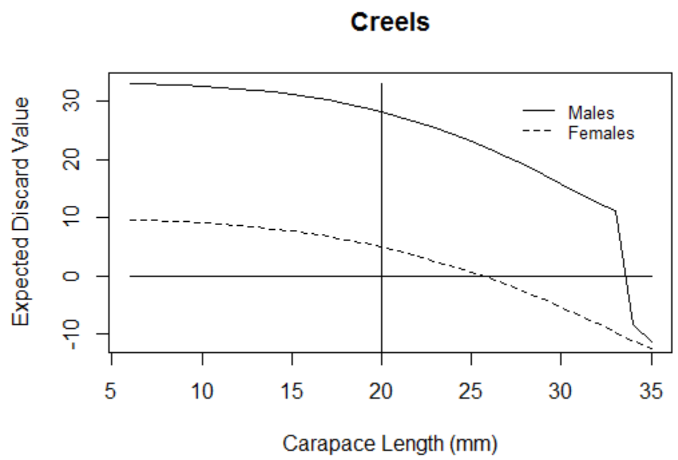

Figure 39: Current estimate of the value of releasing a Nephrops assuming an overall 10% chance of recapture. Retention should occur optimally when the expected discard value = 0 or less.

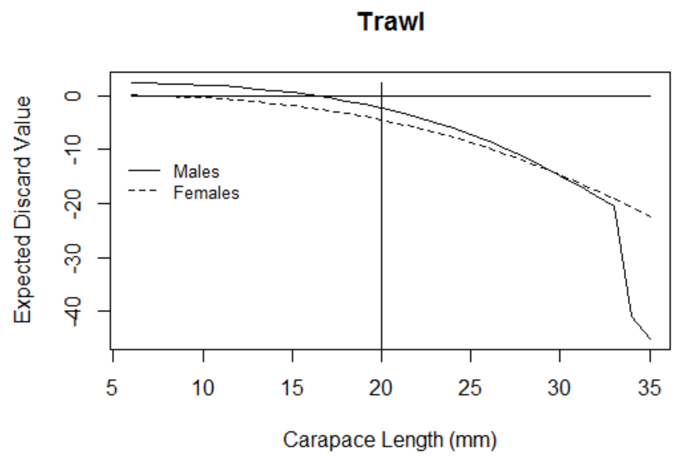

Figure 40: Expected discounted benefits of the value of releasing a Nephrops assuming an overall 10% chance of recapture after a 75% discard mortality.

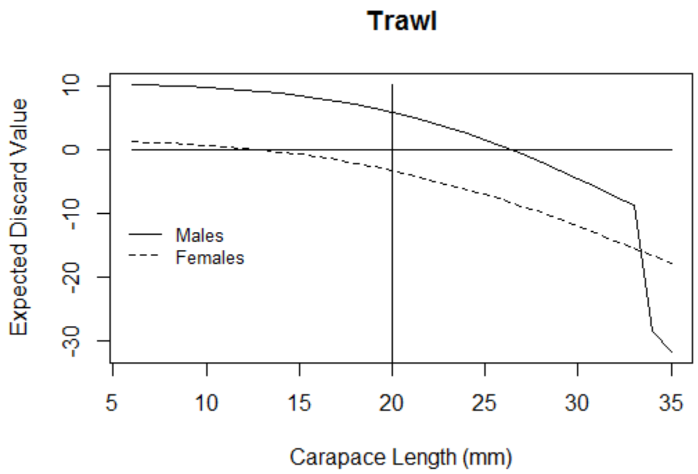

Figure 41: Expected benefits of the value of releasing a Nephrops assuming an overall 10% chance of recapture with no discard mortality.

11.4 Gear Interactions

It is clear from these analyses that there is significantly higher benefit for higher MLS for creel compared to that for trawl. In addition, because trawl tend to select smaller *Nephrops* trawl catches will tend to reduce creel catch rates as fewer animals reach the sizes selected by creels. Furthermore, any general increase in MMLS would tend to benefit the creel fishery far more than the trawl fishery.

If around 25% of overall catches can be attributed to creels (broadly consistent with landings in recent years), the probability that a *Nephrops* randomly selected from the catches was caught by creel given its size and sex can be estimated from gear selectivity functions or arrays. This allows us to estimate which gear is affected by different MLS, including the loss (having to discard) and the benefits (recapture) for different size *Nephrops*.

Taking into account the likely losers (which gear would have to discard most) and winners (which gear is likely to gain from the recaptures) confirms significant losses to trawl and gains to creels with cross sector increases in MLS. MLS up to 25mm mostly impacts trawl since these are much more rarely caught by creel. However, this result assumes 75% discard mortality for trawls. If mortality could be reduced more efficiently at smaller sizes, for example by reducing trawl activity rather than discarding, there could be higher benefits for both gears.

11.5 Scenarios

The yield per recruit approach can also be used to explore the possible impact of the scenarios proposed in the previous section.

11.5.1 Scenario 1: Overall reduction in capture of small prawns

In this scenario, a scheme would be introduced to encourage reduced catch primarily of smaller prawns (less than 30mm) for the whole fishery as described in section 10. This would really only affect the trawl fleet since the market for live prawns (creelers) will not accept animals less than 32mm CL. Assuming the trawl was operating on a separate stock, the benefits and losses to trawl can be considered separately. In this scenario, a proportional selectivity change would take place across all size classes, but would predominantly reduce smaller *Nephrops* catch. Three selectivity changes are considered under this scenario (Table 11), with a base case, and more optimistic and less optimistic scenarios in terms of the effectiveness in reducing relative number so small *Nephrops* in the catch.

The expected value of the Nephrops which are not caught can be estimated by adjusting the selectivity according to each scenario, with an additional scenario “Now” where there is no adjustment. In all the scenarios, the management changes to selectivity result in a relative fall in the expected total value of the catch for trawl (Figure 42). The fall in catch rates within these scenarios offsets any gains in utility per recruit.

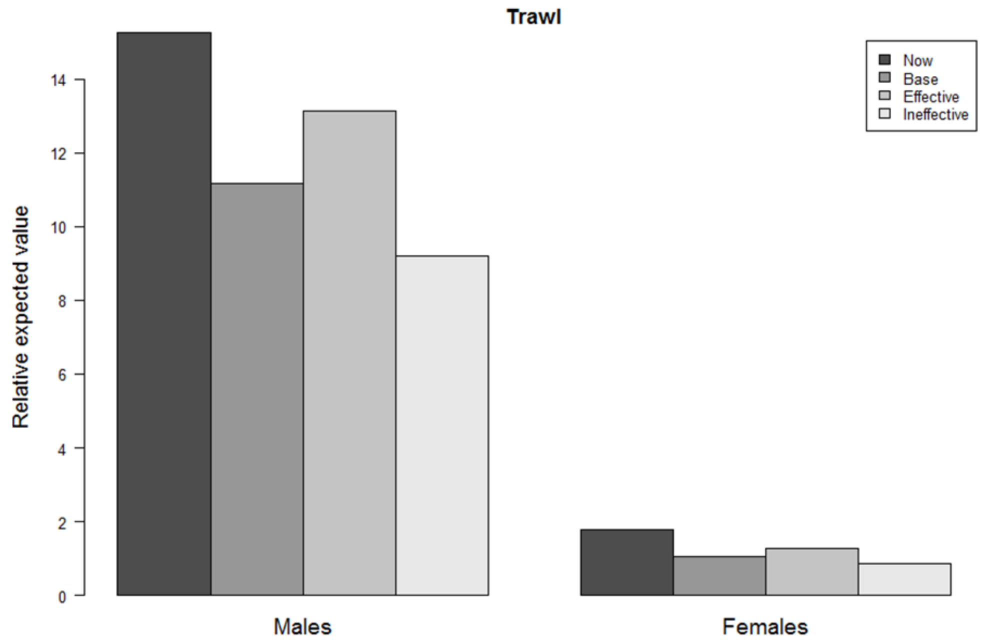

Figure 42: Expected catch value standardised relative to the average value of the “>50 count/kilo” commercial category for the four alternative scenarios representing different management interventions for trawl.

11.5.2 Scenario 2: 40mm MLS for the creel fishery

Under this scenario the catch or take profile of the creel fishery is unchanged except for animals under 40mm (24pc/kg) which becomes approximately zero. In this scenario, for the current exploitation rate, an overall loss might be expected according to Figure 39. However, given the overall exploitation rate is managed by a landings TAC, the exploitation rate could increase for animals over 40mm, although this might require more creels to increase landings proportionately with unknown increases in costs.

For a 40mm MLS, the increased probability of recapture implies the maximum value will be reached for males at a harvest ratio around 0.2 as opposed to the current harvest ratio set at 0.1-0.15. Female growth would imply an unrealistic and possible unsustainable harvest ratio at 0.5 to maximise value, although the MLS will be set well above the size at maturity (22mm CL).

11.6 Longer term stock health and yield benefits for Nephrops

In terms of longer term benefits to overall stock health, recruitment and fishery yield, the available data does not allow us to go beyond the stock assessments already conducted by Marine Scotland Science and ICES (2013). These suggest that the North Minch Nephrops fishery is being fished sustainably and at a level commensurate with maximum sustainable yield. The stock appears to be well above $B_{trigger}$, and overall fishing mortality appears to be below F_{msy}. However, there is substantial uncertainty relating to the total area of habitat (and therefore total stock estimates) and the nature of and status of possible subsidiary stocks at local level.

11.7 Velvet Crabs

A preliminary decision analysis was carried out on velvet crabs, for which information was more limited. It follows the same methodology as that applied to *Nephrops*, although price, growth and other parameters have changed accordingly (see Annex 4 for details).

The velvet crab analysis is less complex than *Nephrops* as it does not have to account for changes in growth with maturity in females, and there is only one gear (creels). Furthermore, male and female growth is very similar, so there is little change in length-at-age. However, the length-weight relationship is different, so the change in value with length and age differs between the sexes.

A simple selectivity-mortality model was developed which accounted for size (carapace width) and sex only (year, month and trip effects were not included). The total mortality estimated from the model was 0.43 year-1, suggesting fishing mortality was around 0.33 year-1 and probability of recapture after release would be around 76%.

For current parameter estimates, the results suggest reducing retention of sizes up to the large category would benefit these fisheries (Figure 43) with an optimal MMLS of around 77mm carapace width. However, these results are heavily dependent on the parameter values used. While exploration of alternative plausible parameter values would help understand sensitivity of results, further work would be required to provide a proper assessment of the risks before an informed decision could be made on this issue.

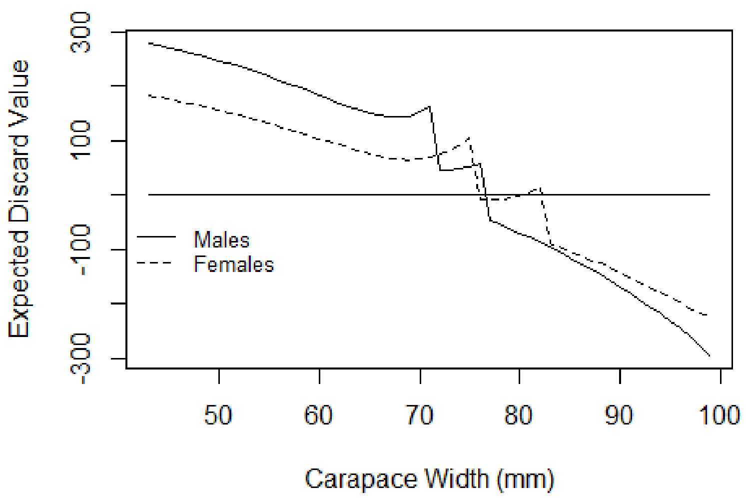

Figure 43: Expected discard value for individual velvet crabs based on carapace width.

Main findings: yield per recruit and decision analysis

- YPR and UPR are simple calculations that capture major factors affecting changes in selectivity, growth and mortality, such as altering MLS or fishing mortality. These PR approaches are fairly inflexible and do not necessarily deal with dynamics or uncertainty well.
- Decision theory is more flexible and able to combine a wide number of features and uncertainty integrating them into a single score. The method can hide complex calculations and critical assumptions however, which need to be carefully documented.
- The results suggest that for current harvest levels, trawl is unlikely to benefit from raising the minimum size unless capture can be avoided without any increase in mortality. Raising MLS for trawls is however likely to benefit the creel fishery.
- Creels could benefit from a larger minimum size overall, which for males, would be retaining catches falling within the 40 or less count per kilo price category (more than 33mm CL). This is in fact current practice, driven by lack of demand for animals below this size
- Similar results are obtained for velvet crabs. In this case, capture of crabs for the “medium” size category could be returned to the sea as recapture probability may be high. However, this needs further work to confirm as estimates natural mortality are highly variable.

12 DISCUSSION AND CONCLUSIONS

12.1 Short term costs and returns for the *Nephrops* Fishery

The modelling strongly suggests that introduction of a MMLS would have significant negative effects on both costs and returns to trawler fishermen, and it would be a simple matter to scale these up for the case study area to illustrate total losses and threats to employment as a result.

This relates to:

- The physical and behavioural characteristics of *Nephrops* and the difficulty of developing size selective trawl gear. There is some evidence from France that gears with grids can be developed to be more selective, but these have not been tested or the results replicated anywhere else to date.
- The dependence of the Scottish Trawl fleet on the high volume/lower value "tails" market. Even if gear were to be more size selective, a large proportion of the catch will still be broken or damaged and have to go to this market.
- There are substantial costs associated with slowing down a trawl and reducing the haul time to improve the quality (and possibly size) of product. At the present time catch per unit effort of high quality whole fresh prawns is inadequate to justify a change of practice, although this could change if the value of whole fresh or frozen prawns increases significantly relative to the price of tails.

An increase in MMLS to 30mm CL would have no negative impact on the creel fleet – it is already implemented in effect because of the lack of market for live prawns below this size.

An increase in MMLS of live prawns up to 40mm in the creel fishery would have a modest negative impact on many creelers (those who are less active, and those that target grounds with slightly smaller animals, and are able to access markets that will accept live prawns less than 40mm CL). Such an increase is however likely to generate benefits to more active creelers, and it is notable that it is current practice amongst some skippers to discard prawns less than 40mm CL, related to the particular markets and traders that they are able to access, as well as to the view that such practice is likely to improve stock health and average size of future catch.

12.2 Medium and long term yield benefits

Yield per recruit and decision analysis suggests that the benefits of discarding or allowing smaller animals to escape and grow into a more valuable size class for future capture would be outweighed by the overall loss of catch (reduced CPUE) for the trawl fleet. This results in part from the high discard mortality, and likely high post-escape (from more selective gear) mortality in the trawl fleet. Without radical improvements in gear selectivity that minimise post-escape mortality, and a significant increase in the price of fresh whole prawns, an increase in MMLS is unlikely to make sense for the trawl fishery.

There would however be significant benefits to the creel fishery of increasing MMLS to 33mm CL. In practice this is already in place within the creel sub-sector, who rarely catch animals below this size, and when they do would normally discard (and achieve high discard survival rates).

Increasing MMLS across the board for a mixed creel/trawl fishery to 25mm or 30mm CL is likely to generate substantial gains to the creel fishery and losses to the trawl fishery. In so far as income and employment per kg landed is significantly higher for the creel fishery compared with the trawl, it is arguable that such a strategy would make long term social economic sense. In practical terms however, the short term disruption to trawler livelihoods would almost certainly be unacceptable. Furthermore, in the absence of highly effective selective gear (the current situation) implementation would involve an increase in discards, which given both the high discard mortality and the requirements of the EU discard ban would make no commercial or management sense.

It was made very clear to us from fishermen, traders and others with a good understanding of the industry that introduction of a consistent MMLS would not be possible where there is a mix of mobile and fixed gear.

In terms of longer term benefits to overall stock health, recruitment and fishery yield, the available data does not allow us to go beyond the stock assessments already conducted by Marine Scotland Science and ICES (2013). These suggest that the North Minch *Nephrops* fishery is being fished sustainably and at a level commensurate with maximum sustainable yield. The stock appears to be well above $B_{trigger}$, and overall fishing mortality appears to be below F_{msy}. However, there is substantial uncertainty relating to the total area of habitat (and therefore total stock estimates) and the nature of and status of possible subsidiary stocks at local level.

12.3 Introducing MMLS at a regional level

The preceding analysis highlights the fundamentally different interests of the creel and trawl sub-sectors in terms of both optimal stock management and product/marketing strategy, and suggests that a greater degree of physical separation, ideally corresponding with (at least partially) subsidiary stocks, would allow for more rational and optimal fisheries management in line with both stock management and marketing strategic needs. Indeed, it is arguable that without such separation, these fisheries cannot be managed optimally from an economic perspective.

Separation would serve the additional purpose of reducing the well-known mobile v static gear conflict issues.

There is undoubtedly significant interest in gear separation zones, and while it is recognised that opposition is vocal, there is no doubt that this would suit the majority of fishermen, reduce conflict, and allow for management agreements suitable for the different sub-sectors.

Such separation could be undertaken based on the old three mile limit approach. However, this would undoubtedly be disruptive to many fishermen – especially trawlers - and implementation would be difficult. A more gradual negotiated approach, introducing new gear specific zones in a staged process, and allowing for adjustment periods, is likely to be both feasible and desirable.

12.4 Velvet crabs

Some preliminary research has been undertaken relating to the desirability of introducing MMLS for velvet crab as prosecuted in the Uists and Barra. Preliminary modelling based on average prices suggests that there is a good case for increasing MMLS to as much as 77mm carapace width. However prices are highly seasonal, and the case for such an increase is greatly reduced at the time of increased demand for all sizes before Christmas. A more detailed analysis taking formal account of seasonality issues would be well worth undertaking.

12.5 Further research

1. The potential value of further research on MMLS for velvet crabs, possibly seasonally based, has already been highlighted.
2. A macro-economic analysis, exploring the overall impact of a generic increase in MMLS in terms of total social and economic costs to the trawl fleet compared with total social and economic gains to the creel fleet would be instructive, and would further inform the debate on the need or otherwise for gear separation zones.

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ANNEX 1: PERSONS CONSULTED

One to one, or group discussions and/or email exchanges took place with the following persons, and their information and perspectives have informed this research. We are very grateful for the help and assistance offered by many in the industry (fishermen, traders, supporting and representative organisations) as well as the research community and Marine Scotland.

The following are on no particular order but roughly grouped according to location and type

Duncan McInnes	W Isles IFG; NW IFG
Richard Greene	Northwest IFG
Katherine Logan	Northwest IFG
John Cox	Moray Firth and N Coast IFG (Chair)
Neil Robertson	Representing non-affiliated fishermen
Duncan Finlayson	North West Responsible Fishermans Association; creel fisherman
Walter van Goul	North West Responsible Fisherman's Association
Alasdair Phillips	Skipper (creel). North West Responsible Fishermans Association
Kenny Livingston	Torridon Nephrops Management Group; Sheildaig Exports
Ali MacLeod	Inshore Fishermen's Association Torridon and Applecross; part-time creel fisherman
John Britten	Skipper (creel)
Roy McGregor	Skipper (trawl)
Donald Matheson	Skipper (trawler)
Alistair McKinnon	Investor (creel boat owner)
Kenny Lamont	Skipper (trawler)
Keith Stewart	Skipper (trawl)
Angus Mcleod	Skipper (creeler)
James Corrigall	Skipper (trawler)
Bruce Langlands, NW IFG meeting?	Skipper (creels, nephrops, crab; mackerel)
Kevin Peach	Harbourmaster, Ullapool

Mairi Evans	Seafood trader, Just Hooked
Angus Campbell	Kilbride Shellfish
Angus McIntyre	Kilbride Shellfish
Hector Stuart	Kallin Shellfish
Willie Macdonald	Boat owner and trader/live storage
Miguel Rivera/Emilio Rivera	Imex International
John Mackay	Harbourmaster, Burghead
Bill West	Gardenstown Line & Static Gear Assoc
Edwin Flett	Gardenstown Line & Static Gear Assoc
Marius Anderson	Skipper, Burghead (trawl)
Alan Donn	Burghead (skipper, trawl)
MD	DFDS/STEF seafood
Alasdair Hughson	Keltic Seafare
Bill Mitchell	Keltic Seafare
Mark Watson:	Facility Manager, Celtic Shellfish
Javi Martinez	Ex-Scotwest's buyer + boat owner
Robert Thomso	Harbourmaster, Kyle
Colin Alsto	Harbourmaster, Portree
Donnie Macrae	Fisherman, Kyleakin
Maggie Gillies	Scotwest's administrative assistant
	DR Collins
Mark Lawton	Keltic Seafare in Kyleakin
Ronald Scordia	Angelbond
Ismael Paz	Ex-Marescot's buyer; vivier operator
Diego Insua	Mariscos Finisterre; vivier truckoperator
Duncan Mackerlich	
John Mackay	Burghead
Mike Montgomerie	Seafish, Gear specialist
Anne McLay	Marine Scotland Science Aberdeen
Helen Dobby	Marine Scotland Science Aberdeen
Carlos Mesquita	Marine Scotland Science Aberdeen

Jim Drewery	Marine Scotland Science Aberdeen
Lewis Cowies	Seafish
Hazel Curtis	Seafish
Clair Dean	Seafish
Uilleam Fraser	Marine Scotland
David Turnbull	Marine Analtical Unit
Valerie West	Marine Analtical Unit

ANNEX 2: CATCH PROFILES ADJUSTED TO LANDED PRODUCT PROFILES

A set of spreadsheet tables converts the baseline catch profile in terms of numbers (e.g. as shown in figures 13-16 of the main report) to proportion of landed weight by product category. This can then be converted into landed value (per kg) by multiplying the product array by the value array as presented in section 9 of the main report. For the creel fishery this is relatively straightforward since almost all the product is live whole. For the trawl fishery an adjustment has to be for the fate of the prawns (as illustrated in figure 17 main report) and the tail yield. The catch profile can then be modified to explore the possible impact on returns per kg of product of introduction of MMLS or changes related to modified gear or fishing practice.

Table A2.1: Baseline catch profile of creel fishery converted to product profile (numbers)

Size (count per kilo)	cl	female		male		total	
4-7	60 - 70	0	0	115	1%	115	0%
5-9	54-67	10	0%	1400	6%	1410	5%
10-15	48-54	400	4%	4980	23%	5380	17%
16-20	42-47	2655	28%	9040	41%	11695	37%
21-30	38-41	3600	39%	4050	18%	7650	24%
31-40	34-37	1600	17%	1530	7%	3130	10%
41-50	32-34	540	6%	470	2%	1010	3%
>50 discard	<32	500	5%	385	2%	885	3%
	20-25	15	0.2%	15	0.1%	30	0%
	<20	2	0%	1	0.005%	3	0%
Totals		9322		21986		31308	

Table A2.2: Creel catch: Percentage by weight of different landed product categories

Percentage of total weight				
Size (count per kilo)	CL	Live	Enhanced discard	Normal discard
4-7	60 - 70	1.2%		
5-9	54-67	11.5%		
10-15	48-54	24.6%		
16-20	42-47	38.2%		
21-30	38-41	17.5%		
31-40	34-37		5.1%	
41-50	32-34		1.3%	
50-100	<32			0.7%
100-200	20-25			0.0%
>200	<20			0.0%

Table A2.3: Baseline catch profile of trawl fishery converted to product potential profile

Commercial category		Female		Male		Total	
Size (count per kilo)	carapace mm	No.	%	No.	%	No.	%
4-7	60 -70	-	0%	10	0%	10	0.00%
5-9	54-67	-	0%	1,000	0%	1,000	0.14%
10-15	48-54	1	0%	5,750	2%	5,751	0.82%
16-20	42-47	7,000	2%	15,000	5%	22,000	3.13%
21-30	38-41	25,000	7%	51,000	15%	76,000	10.80%
31-40	34-37	41,250	11%	50,000	15%	91,250	12.97%
41-50	32-34	104,000	28%	64,000	19%	168,000	23.88%
>50 (scramble)	<32	150,000	40%	120,000	36%	270,000	38.38%
	20-25	44,000	12%	20,000	6%	64,000	9.10%
discard	<20	3,000	1%	2,500	0.8%	5,500	0.78%
Totals		374,251	100%	329,260	100%	703,511	100%

Table A2.4: Fate of prawns of different size categories (approximated from Drewery et al 2015)

	Fate		
Size (count per kilo)	whole	tails	discard
4-7	98%	1%	1%
5-9	96%	3%	1%
10-15	89%	10%	1%
16-20	74%	25%	1%
21-30	56%	43%	1%
31-40	32%	64%	4%
41-50	13%	78%	9%
50-100	4%	67%	29%
100-200	1%	43%	56%
>200	0%	10%	90%

Table A2.5 Catch (numbers) adjusted to product after applying fate factor from table A2.4

		Proportion of trawl catch	Proportion of ***catch*** by product and size		
Size (count per kilo)	CL	%	whole	tails	discard
4-7	60 -70	0.0%	0.00%	0.00%	0.00%
5-9	54-67	0.1%	0.14%	0.00%	0.00%
10-15	48-54	0.8%	0.73%	0.08%	0.01%
16-20	42-47	3.1%	2.31%	0.78%	0.03%
21-30	38-41	10.8%	6.05%	4.65%	0.11%
31-40	34-37	13.0%	4.15%	8.30%	0.52%
41-50	32-34	23.9%	3.10%	18.63%	2.15%
50-100	<32	38.4%	1.54%	25.71%	11.13%
100-200	20-25	9.1%	0.09%	3.91%	5.09%
>200	<20	0.8%	0.00%	0.08%	0.70%
Totals		100%	18%	62%	20%

Table A2.6: Derived proportion of product by weight (trawl)

CL	Size (count per	whole	tails	discard
60 -70	4-7	0%	0%	0%
54-67	5-9	1%	0%	0%
48-54	10-15	4%	0%	0%
42-47	16-20	10%	1%	0%
38-41	21-30	18%	5%	0%
34-37	31-40	9%	6%	1%
32-34	41-50	5%	10%	4%
<32	50-100	2%	9%	11%
20-25	100-200	0%	1%	3%
<20	>200	0%	0%	0%
	all	50%	31%	19%

ANNEX 3: SHORT TERM IMPACTS OF SCENARIOS ON FINANCIAL PERFORMANCE

Table A3.1: Basic input prices, all scenarios

Variable costs rates and prices- all scenarios			
	Both	**Creel**	**Trawl**
Fuel £/l	0.55		
Skilled labour rate £/day	150		
Food £/day/crew		7	7
Baits cost £/pot hauled		0.03	
Boxes and ice £/kg/das		7	4
Commission % sales			2%
other fishing expenses £/das		50	100
Cost of creels (£/creel)		20	
Life of creels (yrs)		7	
Annual creel maint costs (£/creel)		2	

Table A3.2: Parameter values for different scenarios and sub-scenarios

Most likely	Parameter	<10m creel (<100das)	<10m creel >100 das	<10m trawl	12m trawl	15m trawl
Baseline	Fuel l/das	50	70	191	330	402
Scenario 1				191	330	402
Scenario 2		105	150			
Pots/vessel baseline		300	900			
Pots/vessel scenario 2		600	1200			
Baseline	Pots hauled/day	300	600			
Scenario 1						
Scenario 2		300	600			
Baseline	Soak time	1	1.5			
Scenario 1		1	1.5			
Scenario 2		2	2			
Baseline	catch kg /100 pot ha	10	10			
Scenario 1		10	10			
Scenario 2		10	10			
Baseline	trawl hrs/day			8.00	8.50	10
Scenario 1ml				6.00	6.00	9
Scenario 1o				7.00	7.25	9.50
Scenario 1p				5.00	5.00	8.00
Baseline	catch kg /hr trawl			20	30	40
Scenario 1ml				13	20	26
Scenario 1o				15	22	30
Scenario 1p				11	16	21
Baseline	catch kg /das	30	60	160	255	400
Scenario 1ml				79	118	236
Scenario 1o				105	163	285
Scenario 1p				53	80	171
Scenario 2		30	60			

Table A3.3: Adjustment factors for scenario sensitive basic costs

Scenario dependent adjustment factors for values and costs S1 trawl			
Cost category	**Most likely**	**Optimistic**	**Pessimistic**
Capital value - intangible	1.1	1.3	1
Repairs, gear costs, hire and maintenance	1.1	1.15	1

Table A3.4: Adjustment factors for trawl catch profile Scenario 1

Impact of Scenario 1 on CPUE by size category			
carapace mm	Most likely	Optimistic	Pessimistic
60 - 70	0.85	0.9	0.8
54-67	0.85	0.9	0.8
48-54	0.8	0.9	0.6
42-47	0.8	0.9	0.6
38-41	0.8	0.9	0.6
34-37	0.7	0.8	0.5
32-34	0.6	0.7	0.5
25-32	0.5	0.6	0.5
20-25	0.5	0.4	0.5
<20	0.5	0.4	0.5

Table A3.5: Adjustment factors for creel catch profile scenario 2

Impact of S2 on CPUE by size category	
60 - 70	1.2
54-67	1.2
48-54	1
42-47	0.8
38-41	0.8
34-37	0
32-34	0
<32	0

Table A3.6: Baseline financial performance

	<10m creel (<100das)	<10m creel >100 das	Portree <9.9m trawl	Portree 12m trawl	Portree 14.5m trawl/visit
Vessel characteristics					
Length	7.5	8.5	9.8	12.1	14.8
Age	26	23	32	31	37
Power	59	99	89	148	163
Creels	300	900			
DAS	45	172	148	159	158
Fuel/das	50	70	191	330	402
No of creels/day	300	600			
DAS var	45	172	148	159	163
Catch/das	30	60	160	255	400
Avg value/kg of catch	10.44	10.44	3.78	3.78	3.78
Crew	1	1.5	1.8	2.5	3
Insurance	295	1,108	2,157	3,763	-
General repairs, gear costs, hire and maintenance	1,163	6,344	13,589	15,751	-
Creel repairs and maintenance	600	1,800			
Other vessel expenses	973	4,232	6,461	7,308	-
Total vessel expenses	**3,031**	**13,484**	**22,207**	**26,822**	**46,000**
Fuel	1,238	6,622	15,547	28,859	36,039
Labour	6,750	38,700	39,960	59,625	73,350
Commission	282	2,155	1,791	3,066	4,931
Harbour dues	125	593	1,340	2,735	3,200
Boxes and ice	210	420	640	1,020	1,600
Bait	405	3,096			-
Crew travel and food	315	1,806	1,865	2,783	3,423
Quota leasing	3	20	33	134	150
Other fishing expenses	2,250	8,600	14,800	15,900	16,300
Total fishing expenses	11,577	62,012	75,976	114,121	138,993
Total expenses	14,608	75,496	98,183	140,943	184,993
Sales income	14,093	107,732	89,543	153,316	246,546
Gross Profit	-516	32,236	-8,640	12,373	61,553
Depreciation	3100	2300	6000	6500	7000
Creel depreciation	857	2,571			
Interest	1000	1000	1000	1000	1500
other finance					800
Total capital/finance	4,957	5,871	7000	7500	9300
Net profit	-5,473	26,365	-15,640	4,873	52,253
Return on labour (£/day)	28	252	91	162	257

Table A3.7: performance of trawlers under Scenario 1 (most likely)

	Portree <9.9m trawl	Portree 12m trawl	Portree 14.5m trawl/visit
Vessel characteristics			
Length	9.8	12.1	14.8
Age	32	31	37
Power	89	148	163
Creels			
DAS	148	159	158
Fuel/das	191	330	402
No of creels/day			
DAS	148	159	163
Catch/das	81	122	244
Avg value/kg of catch	4.02	4.02	4.02
Crew	1.8	2.5	3
Insurance	2,157	3,763	-
General repairs, gear costs, hire and maintenance	14,948	17,326	-
Other vessel expenses	6,461	7,308	-
Total vessel expenses	**23,566**	**28,397**	**46,000**
Fuel	15,547	28,859	36,039
Labour	39,960	59,625	73,350
Commission	967	1,559	3,196
Harbour dues	1,340	2,735	3,200
Boxes and ice	325	487	975
Crew travel and food	1,865	2,783	3,423
Quota leasing	33	134	150
Other fishing expenses	14,800	15,900	16,300
Total fishing expenses	74,837	112,081	136,633
Total expenses	98,403	140,478	182,633
Sales income	48,364	77,938	159,798
Gross Profit	-50,039	-62,540	-22,835
Depreciation	6000	6500	7000
Creel depreciation			
Interest	1000	1000	1500
other finance			800
Total capital/finance	7000	7500	9300
Net profit	-57,039	-70,040	-32,135
Return on labour (£/day)	-64	-26	84

Table A3.8: performance of trawlers under Scenario 1 (optimistic)

	Portree <9.9m trawl	Portree 12m trawl	Portree 14.5m trawl/visit
Vessel characteristics			
Length	9.8	12.1	14.8
Age	32	31	37
Power	89	148	163
DAS	148	159	158
Fuel/das	191	330	402
No of creels/day			
DAS	148	159	163
Catch/das	108	168	293
Avg value/kg of catch	4.01	4.01	4.01
Crew	1.8	2.5	3
Insurance	2,157	3,763	-
General repairs, gear costs, hire and maintenance	15,627	18,114	-
Other vessel expenses	6,461	7,308	-
Total vessel expenses	**24,245**	**29,185**	**46,000**
Fuel	15,547	28,859	36,039
Labour	39,960	59,625	73,350
Commission	1,283	2,141	3,835
Harbour dues	1,340	2,735	3,200
Boxes and ice	432	671	1,173
Crew travel and food	1,865	2,783	3,423
Quota leasing	33	134	150
Other fishing expenses	14,800	15,900	16,300
Total fishing expenses	75,260	112,848	137,470
Total expenses	99,506	142,032	183,470
Sales income	64,145	107,061	191,755
Gross Profit	-35,360	-34,971	8,284
Depreciation	6000	6500	7000
Interest	1000	1000	1500
other finance			800
Total capital/finance	7000	7500	9300
Net profit	-42,360	-42,471	-1,016
Return on labour (£/day)	-9	43	148

Table A3.9: performance of trawlers under Scenario 1 (pessimistic)

	Portree <9.9m trawl	Portree 12m trawl	Portree 14.5m trawl/visit
Vessel characteristics			
Length	9.8	12.1	14.8
Age	32	31	37
Power	89	148	163
DAS	148	159	158
Fuel/das	191	330	402
No of creels/day			
DAS	148	159	163
Catch kg /das	54	81	173
Avg value/kg of catch	3.93	3.93	3.93
Crew	1.8	2.5	3
Insurance	2,157	3,763	-
General repairs, gear costs, hire and maintenance	13,589	15,751	-
Other vessel expenses	6,461	7,308	-
Total vessel expenses	**22,207**	**26,822**	**46,000**
Fuel	15,547	28,859	36,039
Labour	39,960	59,625	73,350
Commission	627	1,010	2,210
Harbour dues	1,340	2,735	3,200
Boxes and ice	216	324	690
Crew travel and food	1,865	2,783	3,423
Quota leasing	33	134	150
Other fishing expenses	14,800	15,900	16,300
Total fishing expenses	74,388	111,369	135,362
Total expenses	96,595	138,191	181,362
Sales income	31,347	50,515	110,476
Gross Profit	-65,248	-87,676	-70,886
Depreciation	6000	6500	7000
Interest	1000	1000	1500
other finance			800
Total capital/finance	7000	7500	9300
Net profit	-72,248	-95,176	-80,186
Return on labour (£/day)	-121	-89	-14

Table A3.10: performance of creelers under Scenario 2 (most likely)

	<10m creel (<100das)	<10m creel >100 das
Vessel characteristics		
Length	7.5	8.5
Age	26	23
Power	59	99
Creels	600	1200
DAS	45	172
Fuel/das	50	70
No of creels hauled/day	300	600
DAS var	45	172
Catch/das	30	60
Avg value/kg of catch	11.17	11.17
Crew	1	1.5
Insurance	295	1,108
General repairs, gear costs, hire and maintenance	1,163	6,344
Creel repairs and maintenance	1,200	2,400
Other vessel expenses	973	4,232
Total vessel expenses	**3,631**	**14,084**
Fuel	1,238	6,622
Labour	6,750	38,700
Commission	302	2,306
Harbour dues	125	593
Boxes and ice	210	420
Bait	405	3,096
Crew travel and food	315	1,806
Quota leasing	3	20
Other fishing expenses	2,250	8,600
Total fishing expenses	**11,597**	**62,163**
Total expenses	**15,228**	**76,247**
Sales income	**15,082**	**115,293**
Gross Profit	**-146**	**39,046**
Depreciation	3100	2300
Creel depreciation	1,714	3,429
Interest	1000	1000
other finance		
Total capital/finance	5,814	6,729
Net profit	-5,960	32,318
Return on labour (£/day)	18	275

ANNEX 4: POTENTIAL STOCK AND YIELD BENEFITS

13.1 Introduction

The basis for considering the impact of minimum landing size (MLS) has been the subject of analysis in fisheries science since its inception. The main methodology has been yield-per-recruit approaches, which match growth and mortality to estimate potential yield from a stock under different age selectivity and mortality rates. The basic approach (Thompson and Bell 1934) is now very simple to apply (e.g. FAO 2015) and can be extended to account for various uncertainties.

A useful extension proposed here is to use decision theory to help reduce complexity and identify optimal solutions. Although a little more complex internally, using decision theory is a better approach as it deals with uncertainties explicitly and is more flexible, so that a wide range of factors which might be considered important can be accounted for. Because the methodology integrates the uncertainties into the analysis, the results can be presented in simpler ways.

It should be noted that the best approach to use, where possible, is population dynamics model fitted to the available data, as would be done in a catch-at-age stock assessment model, for example. Dynamic models can be used to project different management controls, such as changes to MLS, to provide information on outcomes in short and long term scenarios, including possible benefits from increased reproduction. There is inadequate data to support development of a stock-recruitment function for West Coast *Nephrops* or velvet crab populations, so this was not included in the modelling exercise.

13.2 Factors Affecting Decision

13.2.1 Growth and Natural Mortality

Standard growth models and parameters used for stock assessment were used to obtain the expected weight of any animal as a function of time after release.

As indicated in the utility-per-recruit approach, natural mortality is aligned with the discount rate for the basic population model with fixed mortality rate. Furthermore, the model does not and cannot discriminate for other reasons why *Nephrops* may not be recaptured. For this reason, natural mortality is likely to be a minimum rate for the decline in probability of capture with age.

Table 13: Biological parameters taken from FU11 stock assessment (WGCSE 2014):

	Parameter	Value	Units	Original Source
All				
	Discard Survival (trawl)	0.25		Charuau et al., 1982; Sangster et al., 1997; Wileman et al., 1999
	Discard Survival (creel)	1		Wileman et al., 1999; Harris and Ulmestrand (2004); Chapman,1981
Males				
	Growth – K	0.16	/year	Adapted from Bailey and Chapman (1983)
	Growth - L(inf)	70	mm	Adapted from Bailey and Chapman (1983)
	Natural mortality - M	0.3	/year	Morizur, 1982
	Length/weight - a	0.00028		Howard and Hall (1983)
	Length/weight - b	3.24		Howard and Hall (1983)
	Size at maturity	27	mm	Adapted from Bailey and Chapman (1983)
Immature Females				
	Growth – K	0.16	/year	
	Growth - L(inf)	70	mm	Adapted from Bailey and Chapman (1983)
	Natural mortality - M	0.3	/year	As for males
	Size-at-maturity	22	mm	Queirós et al. (2013)
Mature Females				
	Growth – K	0.06	/year	Adapted from Bailey and Chapman (1983)
	Growth - L(inf)	60	mm	Adapted from Bailey and Chapman (1983)
	Natural mortality - M	0.2	/year	
	Length/weight - a	0.00074		Howard and Hall (1983)
	Length/weight - b	2.91		Howard and Hall (1983)
	Weight at maturity	5.97	g	
	Maximum Average Weight	110.57	g	
	Effective age at maturity	2.36	years	
	t0	5.25	years	

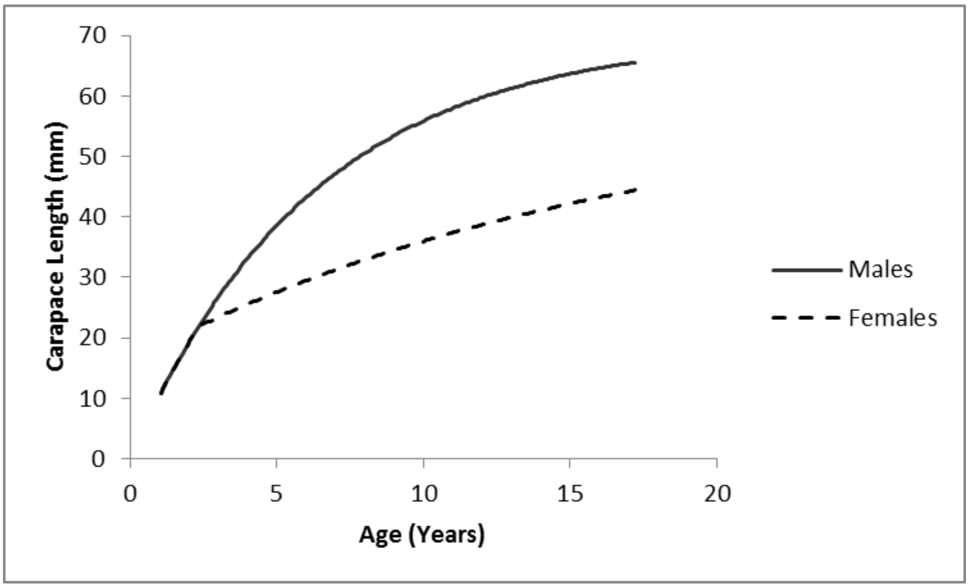

Figure 44: Growth models giving length at age for males and females (from WGCSE 2014)

13.2.2 Fishing Mortality Rate and Selectivity

Catch curves can be used to estimate mean total mortality rates from a sample of aged animals, where the proportion in each age group in the sample represents the proportion of that age in the population. In the case of length converted catch curves use growth models to convert size to age. This introduces another significant source of error. If growth rates are incorrect, the resulting mortality estimates will be biased. Nevertheless, these analyses are worth doing as long as potential errors are considered.

Preliminary estimates for selectivity by gear and other factors were obtained using generalised linear models. Selectivity was estimated from size composition samples. The downward slope on selectivity curves, if any, are confounded with mortality rates. However, in this instance, the outcome for the animal, apart from capture, need not be considered. It would be necessary to consider whether animals not caught by the gear would die or not, if the model included a stock recruitment relationship. Therefore, the “total mortality rate” estimated by the catch curve was not distinguished between natural or fishing mortality, or domed-shaped selectivity.

However, the higher the fishing mortality rate, the higher the chance of capture of any individual animal, and it is necessary to account for this. Therefore the overall chance of capture was scaled to the harvest rates estimated from the stock assessments.

While there are better methods for estimating mortality from catch curves (Dunn et al. 2002), regression methods are the most flexible, particularly as the model can be couched in terms of a generalised linear model (GLM). This allows account to be taken of various factors that affect the estimate, namely the overall sample size, year, gear used, sample type (discard or market), area fished and sex.

The classic approach is to exclude all data from before the *Nephrops* are fully selected. However, selectivity of the gear is often of interest, so no data was excluded from this analysis, but a logistic selectivity curve was fitted alongside the mortality curve. This allowed the model to explore the two parts of the curve related to age. Some simulation work has suggested that estimates of mortality have been improved when modelling logistic selectivity if this selectivity form applies (Thorson and Prager 2011).

The model was fitted using a log-linear model for the mortality (numerator) and a logistic model for the selectivity denominator. This essentially models the upward slope of the frequency separate from the downward slope. In this approach, gear parameters can be fitted as main effects, as well as nuisance parameters to account for the sample size and sampling approach (e.g. market vs discard sampling). Age is estimated for each length and sex category and included as a covariate alongside length.

The GLM uses a non-standard model. Because there are two linear predictors, one each for the selectivity and mortality models, the GLM required another level of iteration to estimate the maximum likelihood parameters. The link model was the log-link and logit link combined:

$$\mu = \frac{e^{M_{lp}}}{1 + e^{S_{lp}}} \tag{1}$$

Where M_{lp} and S_{lp} were the linear predictors for mortality and selectivity respectively. The logistic selectivity is based on length, whereas the mortality is based on the age of each size category.

The “mortality” and “selectivity” models can be fitted alternately until convergence in the deviance is reached. The likelihood used was the Poisson, which is appropriate for counts, such as these data, and more accurate than logging data and applying least-squares for example.

The models were fitted using “glm” functions in R. The selectivity model was included in the mortality model in the offset, which was updated on each iteration. The mortality model was included in the selectivity model as a constant in the link function.

After some exploration, a minimum model was identified appropriate to estimate the full selectivity (Table 14). In the final model, all main terms were included, accounting for gear used, area (stock) fished, sex and whether discards were included in the sample. The analysis of deviance table indicates how much of the deviance that the parameters explain. Exact interpretation of the deviance (log-likelihood) is not possible, but gives some indication of the importance of different effects in explaining the size composition and justification for the selectivity models that result. The full terms consist of nuisance parameters, gear, area, sex and sample type (discard or market trips).

The interaction terms with age or length provide estimates of the downward slope of the frequency (Table 15). All other main effect parameters are nuisance parameters, and account for sample size. The resulting curves are heavily domed shaped, with both gears catching larger males to females, and creels catching larger Nephrops overall (Figure 45).

The analysis was exploratory, and is strictly used to identify a range of suitable selectivity functions and effective mortalities to use in assessing the benefits for changes in MLS. A number of issues remain to be resolved in this type of analysis, most notably the treatment of over-dispersed error.

Table 14: Analysis of deviance table

	Terms	Deviance	df	Deviance Change	df	Deviance Ratio
Mortality	Full	219254.8	3882			
	-Gear	265583.9	3884	46329.1	2	410.14
	-Area	269139.5	3886	3555.6	2	31.48
	-Sex	348765.2	3887	79625.7	1	1409.81
Selectivity	Full	219254.8	3932			
	+Mesh	219227.0	3931	-27.8	-1	0.49
	-Gear	226559.1	3934	7304.3	2	64.66
	-Sex	256830.6	3936	30271.5	2	267.98
	-Discard	664894.2	3938	408063.6	2	3612.47

Table 15:Non-nuisance selectivity (steepness and S50%) and mortality (Z) parameters from the fitted linear model to the available size composition data

Sex	Gear	Sample Trip Type	Logistic Steep-ness	$S_{50\%}$ (mm CL) Minch N	S	Moray	-Z (year^{-1}) Minch N	S	Moray
Males	FP	Landings	1.017	33.11	33.02	25.47	-0.439	-0.492	-0.148
		Discards	0.548	33.15	32.99	18.97			
	OT	Landings	0.727	34.57	34.46	23.88	-1.016	-1.069	-0.726
		Discards	0.258	37.31	36.98	7.21			
Females	FP	Landings	0.920	34.16	34.07	25.71	-0.231	-0.284	0.059
		Discards	0.451	35.30	35.11	18.06			
	OT	Landings	0.630	36.33	36.20	24.00	-0.395	-0.447	-0.104
		Discards	0.161	45.87	45.34	-2.44			

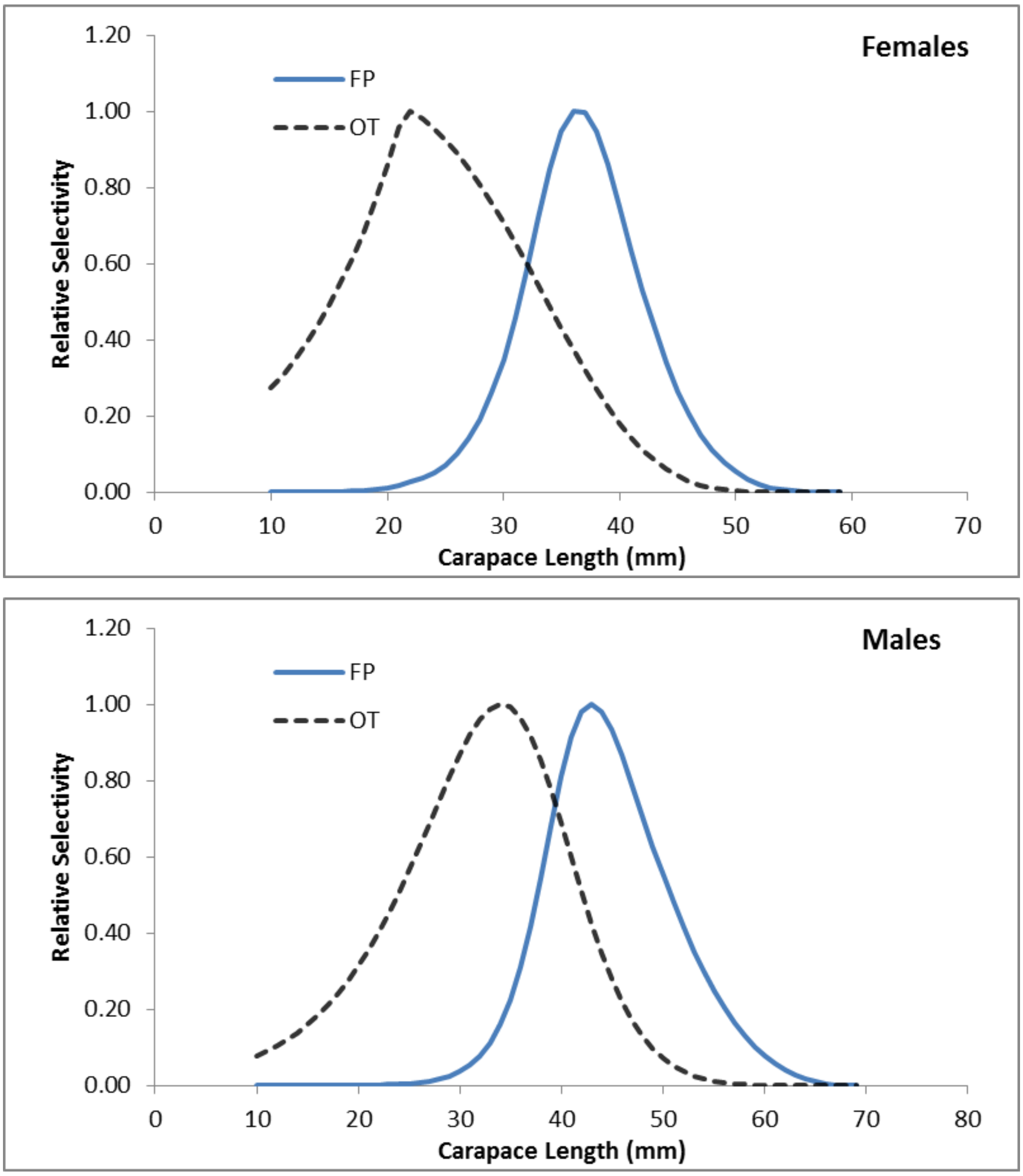

Figure 45: Example of relative selectivity estimated for two gears creels (FP) and trawl (OT) in the North Minch. Note that selectivity here is not separable from mortality rates

13.2.3 Price

Price is primarily affected by size of the product. This is reflected in market "count per kilo" categories, with larger *Nephrops* attracting a significantly higher price (Figure 46, Table 16). This can be accounted for in per-recruit analyses.

Market prices are also affected by supply and demand as well as size, so there is significant variation besides that accounted for by size (Figure 47). For example there is an increase in price of Nephrops in December due to an increase in demand at this time of year. However, price variability over time and the effects of supply are not addressed in this analysis.

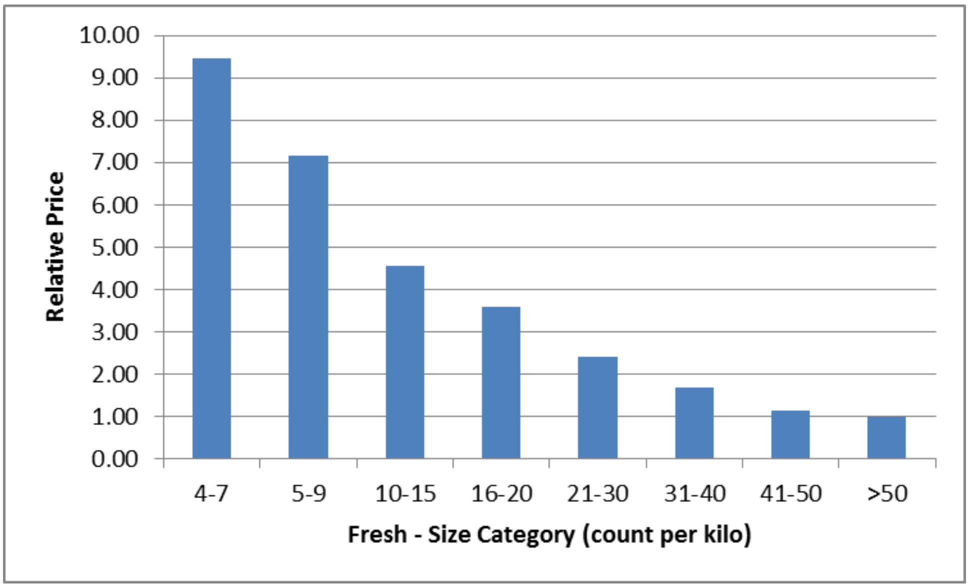

Figure 46: Estimated mean price per kg relative to the >50 count-per-kilo category for the main commercial size categories.

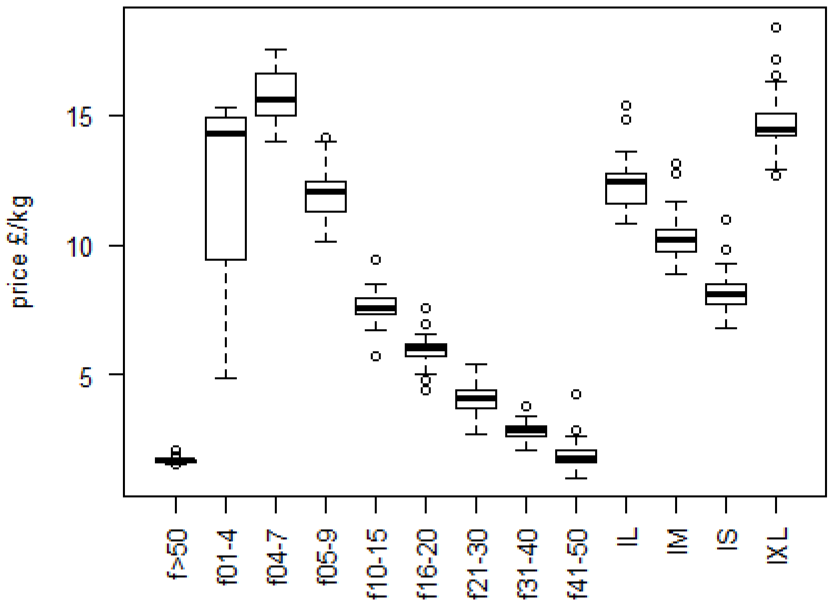

Figure 47 Average and range of prices per kilo as box and whisker plots for the main size categories.

Table 16 Prices and category boundaries used in defining size categories used in the yield-per-recruit (e.g. Nephrops with weights >166.67g belong to the "4-7" category).

Size (count per kilo)	Price Relative to ">50" Category	Lower Weight boundaries (g)
4-7	9.47	166.67
5-9	7.17	105.26
10-15	4.56	64.52
16-20	3.59	48.78
21-30	2.42	32.79
31-40	1.68	24.69
41-50	1.12	
more than 50	1.00	

13.2.4 Discount Rate

Discount rates account for the effects of time on utility. Applying a discount rate allows the present value of future benefits to be estimated. This is convenient in that future dynamics do not have to be explicitly considered, but can be incorporated into results.

Discounting benefits in the models used here works in a very similar way to mortality. High discount rates imply future benefits are worth less, but high discounting is likely to be due to market distortions rather than any real benefits, and assuming low discount rates for public policy reasons (e.g. 3-7% in developed countries) is valid (Zhang *et al.* 2007).

Some inflation was detected in prices, so prices appear to have been gradually increasing over time. Note that price inflation counters discount rate effects, so where interest rates are approximately equal to inflation, discount rates close to zero may not be unreasonable in the current context.

In any case, given the uncertainty in the natural mortality rate, fluctuations and uncertainties in mortality is likely to obscure any effect discounting may have in this context.

13.3 Per-Recruit Analyses

Standard yield-per-recruit estimates can be considered as the expected catch taken from a single cohort. The calculations are based on age intervals i, where $i=(t_i, t_i+\Delta t)$.

The fishing mortality for each age (F_i) is determined by selectivity and natural mortality (M) estimated for the stock from the stock assessment. These can be used to calculate the total mortality:

$$Z_i = M + F_i$$

The mortality is in units of the time step Δt. The numbers at age is estimated from the numbers at the start of the previous age.

$$N_{i+1} = N_i\, e^{-Z_i}$$

In yield per recruit, the number of fish in first age where fish enter the fishery (N_0) equals 1. The catch in weight is given by the numbers caught and their mean weight for each age (W_i). This can be derived from a growth model, or observations on the mean weight at age.

$$C_i = \frac{F_i}{Z_i}(N_{i+1} - N_i)W_i$$

The value of the catch can be estimated from the price per unit weight multiplied by the price for that age.

$$V_i = p_i C_i$$

The total yield or value is found by summing over all the ages i. The advantage of this approach is by using small time steps (Δt), the method can accommodate a wide variety of growth and mortality models.

The per-recruit method accounts for gains from growth and losses from natural mortality in assessing minimum size. It is a simple approach, but can provide useful insight into results. If we assume a fishing mortality of around 0.15 year^{-1}, equivalent to a harvest ratio of 14%, and calculate the yield rate at each age, maximum yields occur at higher size and age for males (Figure 48) due to their higher maximum size. Based on growth and mortality parameters, the size class with the highest biomass in an unfished population (L_{opt}) is 44.5mm for males and 28mm for females. If fishing mortality is allowed to vary, in general, higher fishing mortality requires higher MLS to increase yields (Figure 49).

The differences between males and females become more pronounced in considering price categories as well as growth. The value of males increases faster than females (Figure 50). Males grow to a larger size into the higher price categories, so greater benefits might be obtained by letting them grow compared to females (Figure 51). As a result, the utility per recruit function is dominated by males, with higher revenues indicated for higher MLS (Figure 52), to the extent that females would probably only form a small proportion of the catch at the higher MLS.

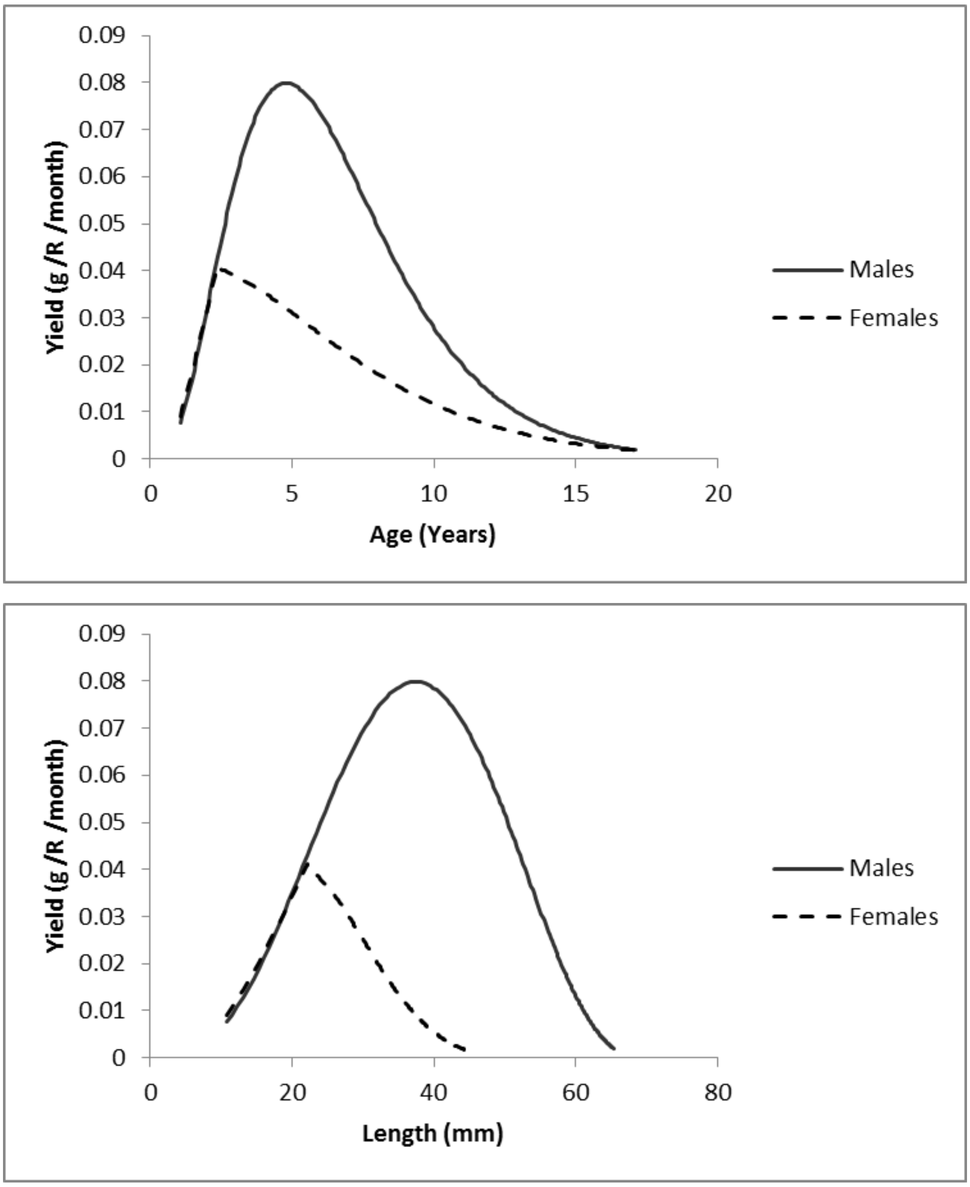

Figure 48: Example yield for males and females as a function of age (top) and length (bottom) based on growth and survival, including an annual harvest ratio of 14%.

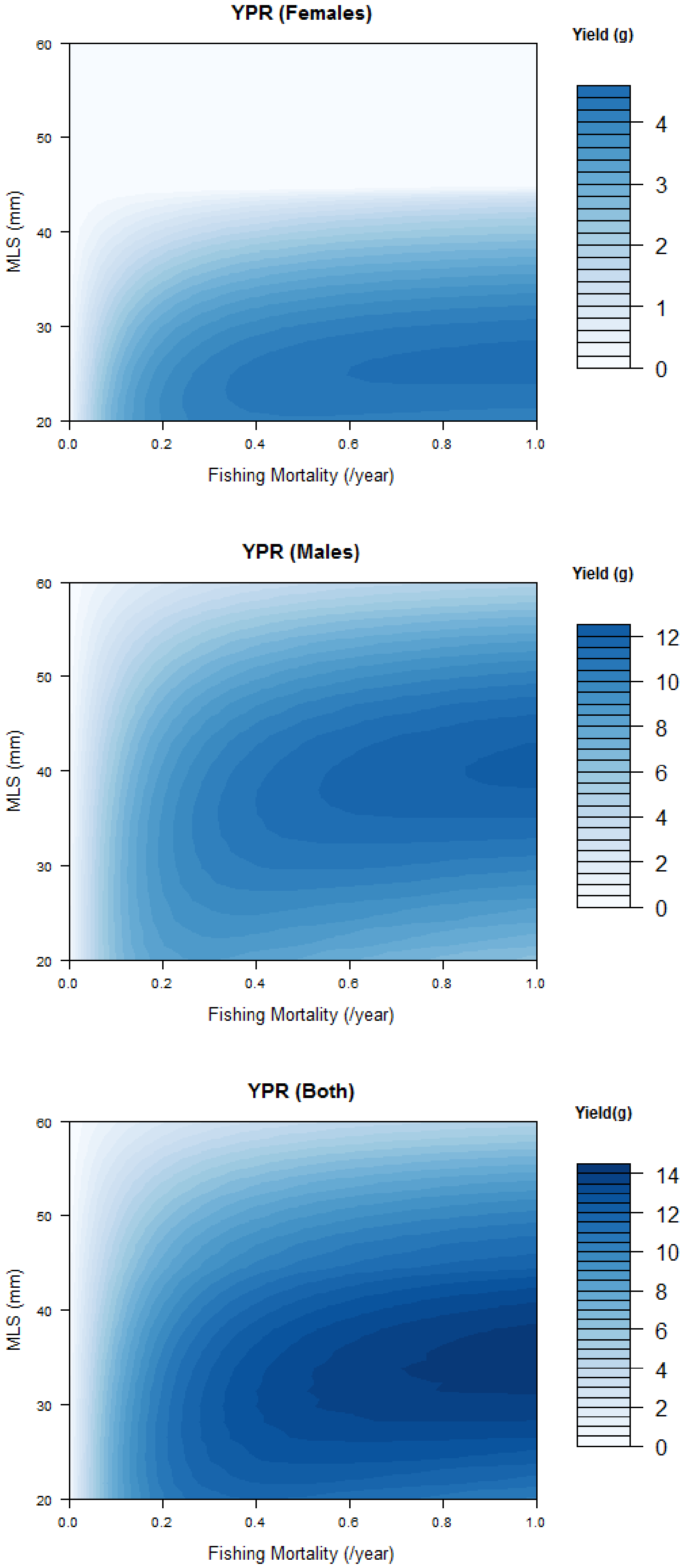

Figure 49: Yield per recruit for Nephrops assuming knife-edge selectivity. For both males and females, a 50% sex ratio is assumed.

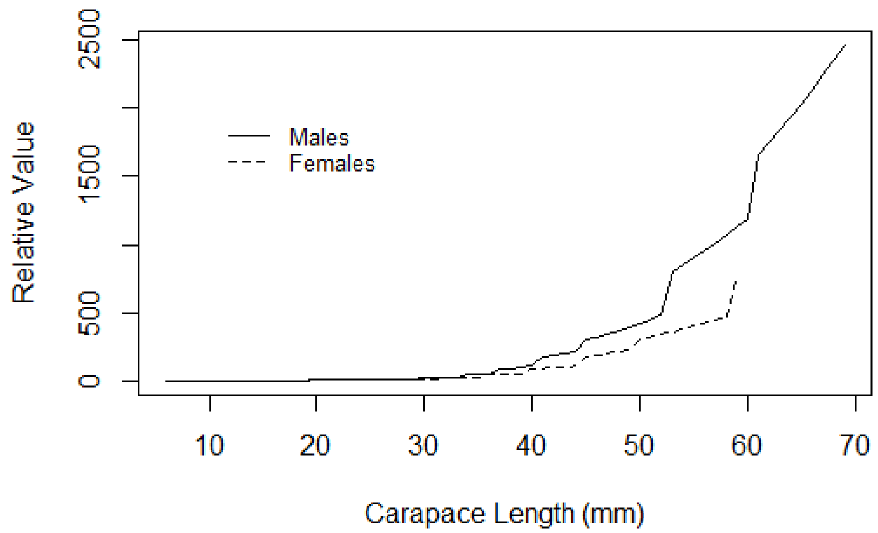

Figure 50: The relative value of individual animals increasing due to their weight and price per gram.

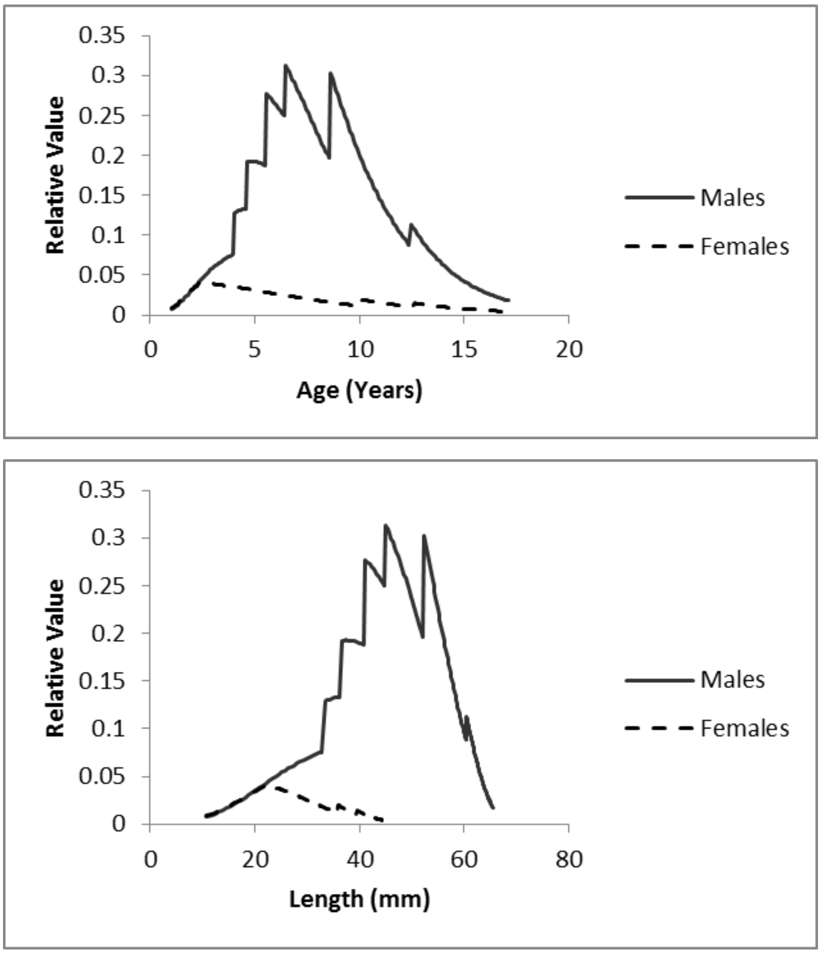

Figure 51: Relative value (utility) for males and females as a function of age (top) and length (bottom) based on growth and survival, including an annual harvest ratio of 14%.

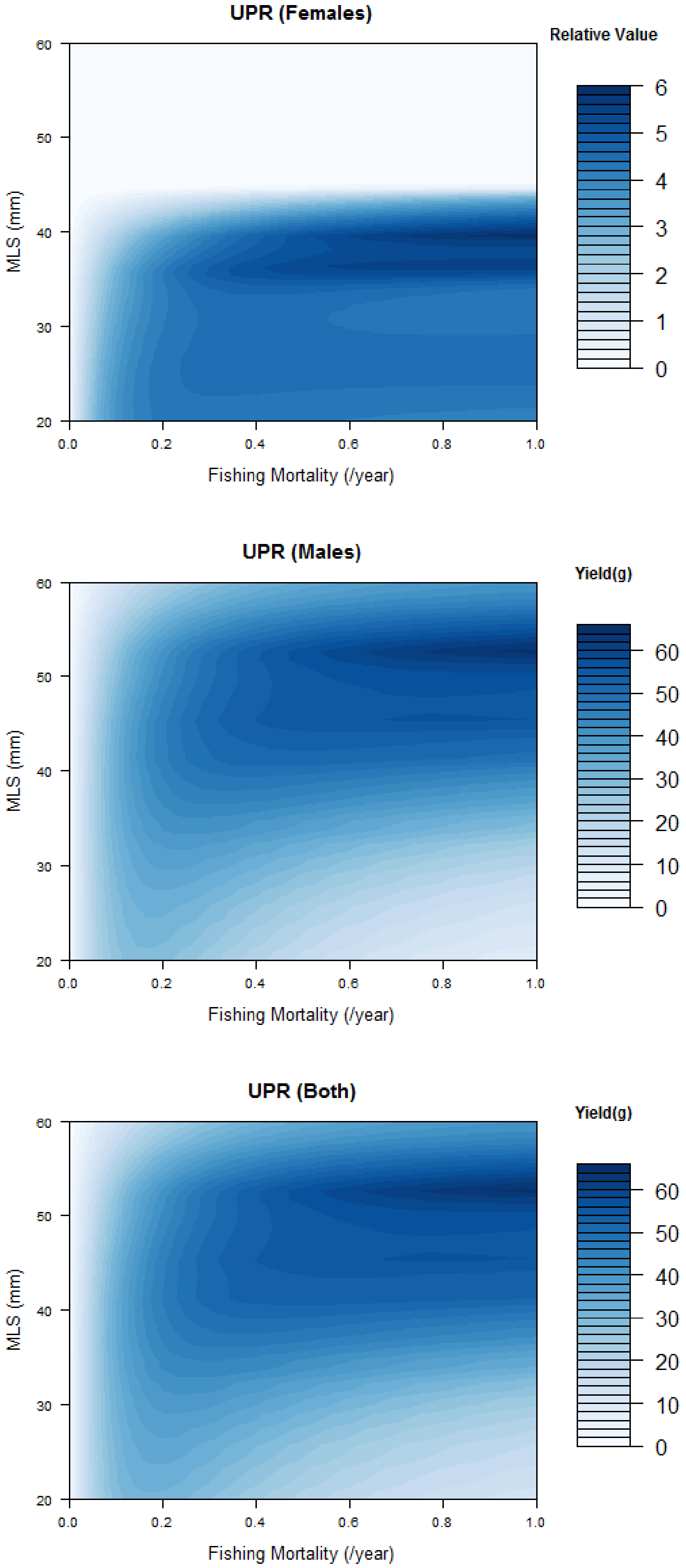

*Figure 52: Utility (price*weight) per recruit for Nephrops assuming knife-edge selectivity.*

13.4 Decision Analysis

The decision theory approach suggests that an animal should be retained if the expected benefit from retaining it exceeds the expected benefit from discarding it or avoiding its capture. The benefit from releasing or avoiding the capture of the animal is the sum over time of the probability of its capture at some future time multiplied by the value of the animal at that time of capture. This basis provides a clearer output in respect of making the decision, where to place the MLS.

A decision analysis can be used to combine various factors including selectivity in a more realistic way than can be achieved through per-recruit approaches, and in particular can account for uncertainty.

Selectivity and mortality are set so that the models are consistent with observed size composition of discards and landings and the stock assessment. These include:

- Growth for males and females, consistent with per-recruit approaches as above;
- Price changes with size;
- Selectivity models for creels and otter trawl

However, the model used here does not include growth variability, errors in the selectivity model or gear interactions (trawl and creels are assumed to be fishing separate stocks). These factors could be considered in future, but may not be the greatest source of error in these models. Most importantly, the assessment used here does not include *Nephrops* stock dynamics such as stock recruitment effects and conservation constraints (e.g. current application of F_{MSY} or use of the survey data). The implication is that the exploitation rate is not considered directly, but input as a fixed parameter.

A higher exploitation rate will generally increase the chance of capture, making higher MLS more beneficial. Significant changes to the current exploitation rate (e.g. increased number of traps, vessels or TAC) could change the value of different MLS. Perhaps a more important consideration is the conservation objective to maintain spawning stock at sufficiently high levels that recruitment would not be impaired. Higher MLS will generally help with this objective, a consideration which may override any yield-per-recruit measures considered in this analysis.

The overall capture probability has been constrained to the exploitation rate set in the stock assessment, so the overall mortality is scaled to the overall capture probability of 14%. As noted above, increasing MLS may allow higher MSY exploitation levels.

After recruitment, the probability of capture within a particular size class beginning at age t_l can be estimated from the available parameters:

$$Pr(Capture\ in\ size = l) \propto Pr(Survival\ to\ t_l)Pr(Capture\ t_l\ to\ t_l + \Delta t_l)$$

Survival is the sum of mortalities to the end of the proceeding size class:

$$Pr(Survival\ to\ t_l) \propto e^{-\sum_l z_l \Delta t_l}$$

The survival can also include a small discount rate. The probability of capture is based on the exploitation rate:

$$Pr(Capture\ in\ l) \propto \frac{F_l\left(1 - e^{-(M+F_l)\Delta t_l}\right)}{M + F_l}$$

The main factor affecting probability of capture within any size class is the selectivity model:

$$F_l = \frac{F}{(1 + e^{S_l})}$$

Where S_l is derived from the model fitted to the size composition data. The overall probability of capture is used to scale F to a number consistent with the harvest ratio:

$$Pr(Capture) = HR = F \sum_l \frac{\left(1 - e^{-(M+F_l)\Delta t_l}\right)}{(M + F_l)(1 + e^{S_l})} e^{-\sum_l Z_l \Delta t_l}$$

For each size class, the transition time can be estimated from the growth model:

$$\Delta t_l = -\,log\left(1 - \frac{L_i}{L_\infty}\right)/K + log\left(1 - \frac{L_{i+1}}{L_\infty}\right)/K$$

Using this, the probability and value of re-capture of any size *Nephrops* can be estimated. The optimum size is the point where the expected benefits for not retaining a *Nephrops* is zero. For creels, where discard mortality is considered negligible, the optimum size for retaining females is around 25mm, and for males is around 34mm CL (Figure 53). This corresponds to retaining males as soon as they enter the 31-40 count per kilo size category. For trawls including discard mortality, suggests that the optimum size for retention is lower than the current MLS (Figure 54). If discard mortality is assumed to be zero, there is some benefit from avoiding capture of males to above 25mm (Figure 55). Technical changes to gear and improved handling would be required to achieve sufficiently low discard mortality to make increased discarding beneficial.

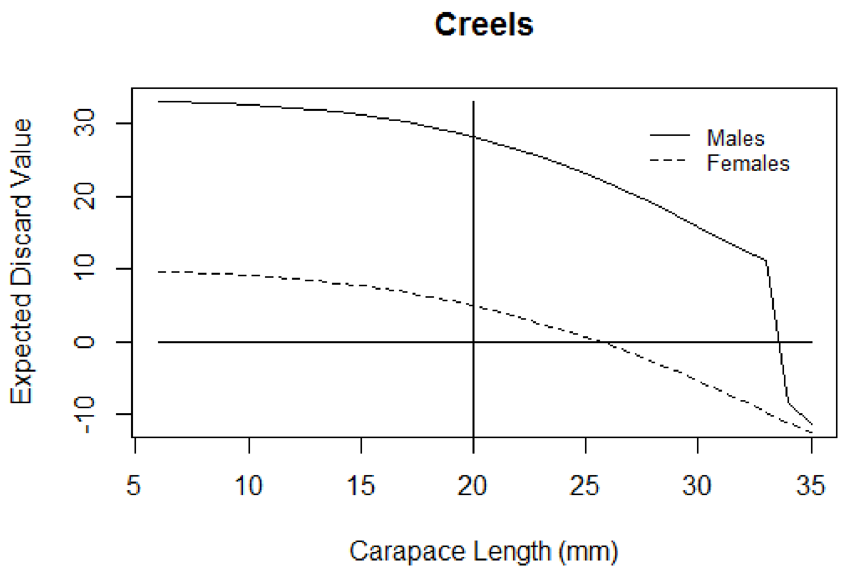

Figure 53: Current estimate of the value of releasing a Nephrops assuming an overall 10% chance of recapture. Retention should occur optimally when the expected discard value = 0 or less.

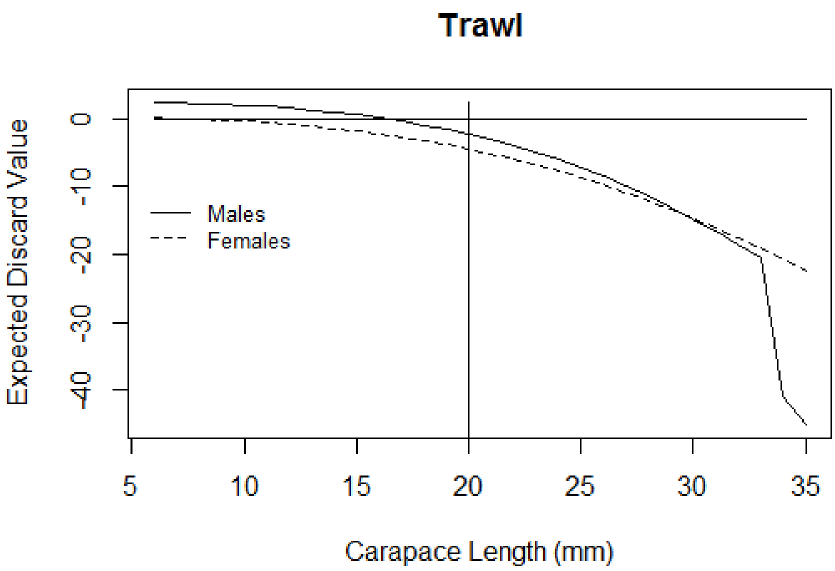

Figure 54: Expected discounted benefits of the value of releasing a Nephrops assuming an overall 10% chance of recapture after a 75% discard mortality.

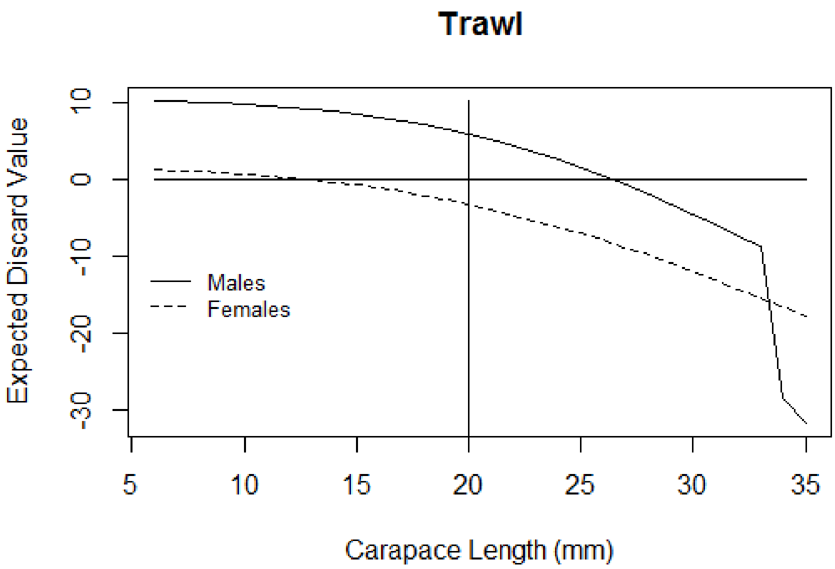

Figure 55: Expected benefits of the value of releasing a Nephrops assuming an overall 10% chance of recapture with no discard mortality.

13.5 Gear Interactions

It is clear from these analyses that there is significantly higher benefit for higher MLS for creel compared to that for trawl. In addition, because trawl tend to select smaller *Nephrops* (Figure 56), trawl catches will tend to reduce creel catch rates as fewer animals reach the sizes selected by creels.

The previous general results above (Section 13.4) would apply regardless of which gear originally caught a *Nephrops* and released it. However, the benefits would be skewed, with gains for the creel fleet and losses for the trawl fleet.

Based on the available catch information (2008-13), creels take around 22% of the landings. We assume that the overall take by creels across all sizes is around 25%. This is approximate because the catch is in weight and does not take into account the size composition. A correction would need to be estimated and applied for this.

If around 25% of overall catches can be attributed to creels, the probability that a *Nephrops* randomly selected from the catches was caught by creel given its size and sex can be estimated from the selectivity functions (Figure 57). This allows us to estimate which gear is affected by different MLS, including the loss (having to discard) and the benefits (recapture) any *Nephrops* at size. Sexes are considered separately as sex ratios in the catches have not been fully accounted for.

Taking into account the likely losers (which gear would have to discard most) and winners (which gear is likely to gain from the recaptures) confirms significant losses to trawl and gains to creels with increases in MLS (Figure 58). MLS up to 25mm mostly impacts trawl since these are much more rarely caught by creel. However, this result assumes 75% discard mortality for trawls. If mortality could be reduced more efficiently at smaller sizes, for example by reducing trawl activity rather than discarding, there could be higher benefits for both gears.

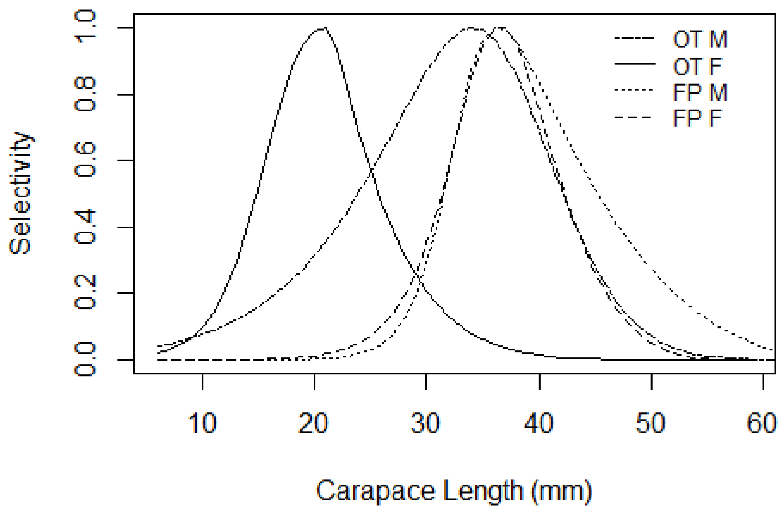

Figure 56: Selectivity curves for trawl (OT) and creels (FP), males (M) and females (F). The curves are rescaled to account for sample size, so represent the relative selectivity for size within each gear and sex.

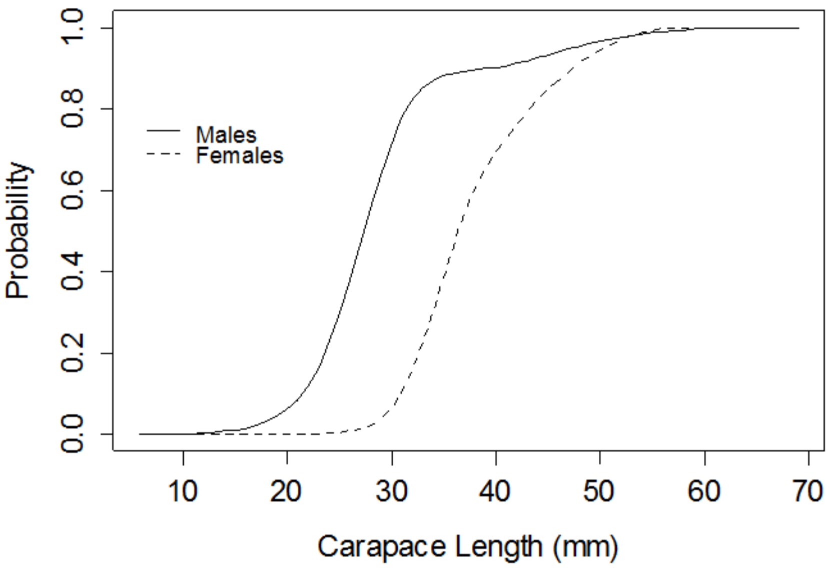

Figure 57: Probability of capture by creel, given the Nephrops is captured and its size and sex. Note that the interaction between size and sex is not accounted for in this approximation.

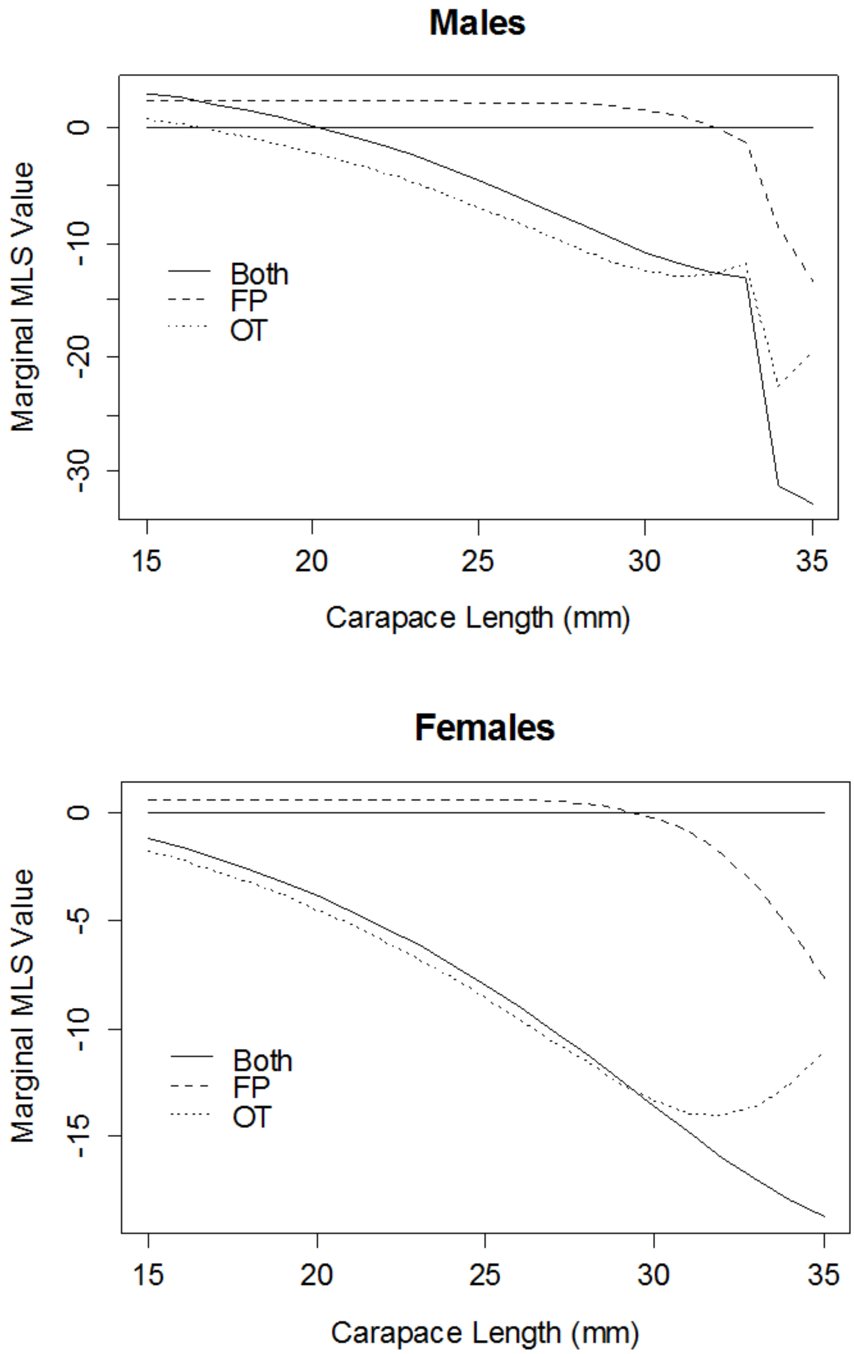

Figure 58: Marginal change in catch value for trawl (OT) and creel (FP) by sex for different MLS as carapace length.

13.6 Scenarios

13.6.1 Scenario 1: Reduced catch of smaller prawns for the whole fleet

In this scenario, a scheme would be introduced which would reduce catch primarily of smaller prawns (less than 30mm) for the whole fishery. This would really only affect the trawl fleet since the market for live prawns (creelers) will not accept animals less than 32mm CL. Assuming the trawl was operating on a separate stock, the benefits and losses to trawl can be considered separately. In this scenario, a proportional selectivity change would take place across all size classes, but would predominantly reduce smaller *Nephrops* catch. Three selectivity changes are considered here (Table 17) with a base case, and more optimistic and less optimistic scenarios in terms of the effectiveness in reducing relative number so small Nephrops in the catch.

The expected value of the *Nephrops* which are not caught can be estimated by adjusting the selectivity according to each scenario, with an additional scenario "Now" where there is no adjustment. In all the scenarios, the management changes to selectivity result in a relative fall in the expected total value of the catch for trawl (Figure 42). So the fall in catch rates within these scenarios offsets any gains in utility per recruit.

Table 17: Relative selectivity changes for base scenario, and two sensitivity analyses for a more and less effective adjustment to selectivity.

Size (count per kilo)	CL (mm)	Base	Effective	Ineffective
less than 5	more than 67	0.85	0.9	0.8
5-9	54-67	0.85	0.9	0.8
10-15	48-54	0.75	0.9	0.6
16-20	42-47	0.75	0.9	0.6
21-30	38-41	0.7	0.8	0.6
31-40	34-37	0.65	0.8	0.5
41-50	32-34	0.6	0.7	0.5
more than 50	less than 32	0.45	0.4	0.5

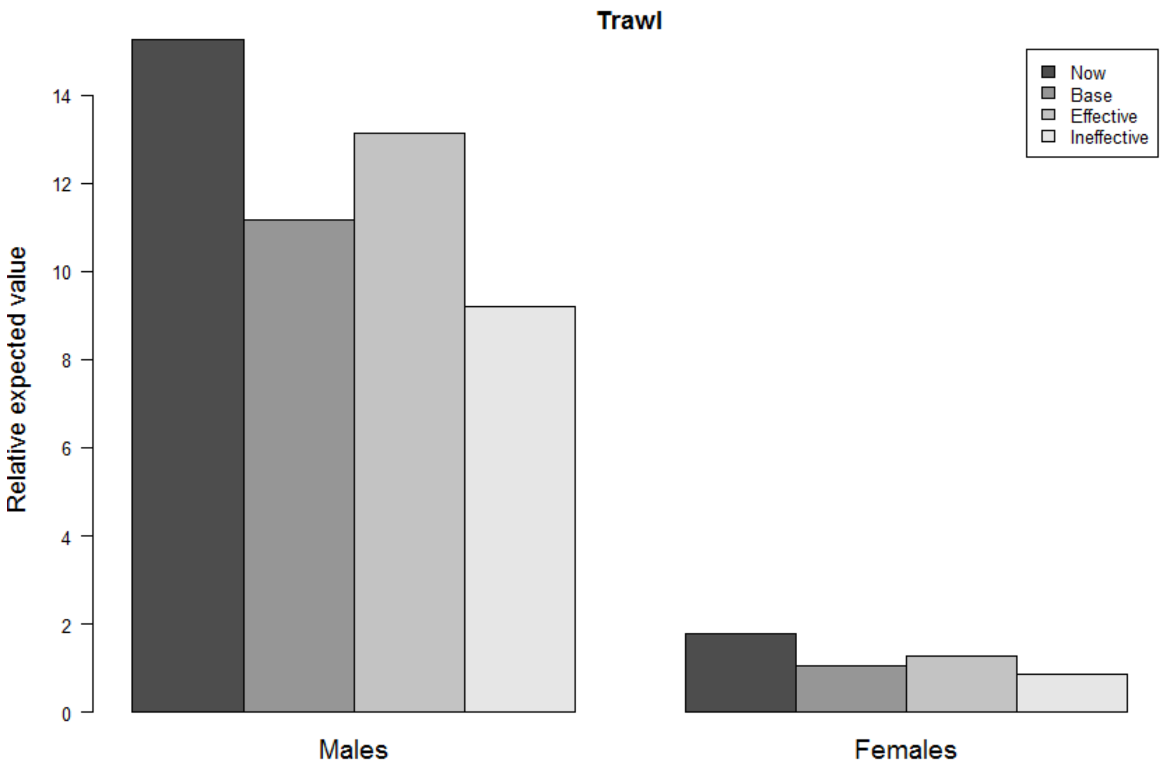

Figure 59: Expected catch value standardised relative to the average value of the “>50 count/kilo” commercial category for the four alternative scenarios representing different management interventions for trawl.

13.6.2 Scenario 2: Introduction of 40mm MLS within creel only zone

Under this scenario the catch or take profile of the creel fishery is unchanged except for animals under 40mm (24pc/kg) which becomes approximately zero. In this scenario, for the current exploitation rate, an overall loss might be expected. However, given the overall exploitation rate is managed by a landings TAC, the exploitation rate could increase for animals over 40mm, although this might require more creels to increase landings proportionately with unknown increases in costs.

For a 40mm MLS, the increased probability of recapture implies the maximum value will be reached for males at a harvest ratio around 0.2 as opposed to the current harvest ratio set at 0.1-0.15. Female growth would imply an unrealistic and possible unsustainable harvest ratio at 0.5 to maximise value, although the MLS will be set well above the size at maturity (22mm CL).

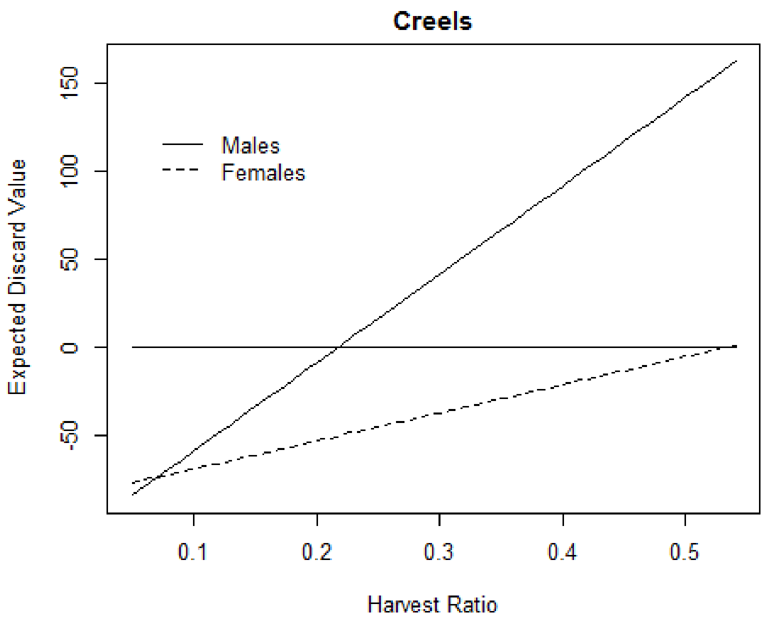

Figure 60: Discard value as a function of harvest ratio for a 40mm CL MLS for creels.

13.7 Velvet Crabs

The decision analysis was also carried out on velvet crabs. Information was more sparse on velvet crabs than Nephrops, so the analysis is preliminary. It follows the same methodology as that applied to Nephrops, although price, growth and other parameters have changed accordingly (Table 18, Table 19).

The velvet crab analysis is less complex than Nephrops as it does not have to account for changes in growth with maturity in females, and there is only one gear (creels). Furthermore, male and female growth is very similar, so there is little change in length-at-age. However, the length-weight relationship is different, so the change in value with length and age differs between the sexes (Figure 61).

The commercial size categories were not well-defined (Figure 62). Weight estimates based on carapace width were used to allocate to category for the available sample data, with carapace width below 130mm being “medium” and above 165mm being “extra-large”.

The selectivity-mortality function was estimated from the available size composition data (Figure 64). A simple model was used which accounted for size (carapace width) and sex only (year, month and trip effects were not included). The total mortality estimated from the model was 0.43 $year^{-1}$, suggesting fishing mortality was around 0.33 $year^{-1}$ and probability of recapture after release would be around 76%. This was used for this exploratory analysis.

For current parameter estimates, the results suggest reducing retention of sizes up to the large category would benefit these fisheries (Figure 64). However, these results are heavily dependent on the parameter values used. While exploration of alternative plausible parameter values would help understand sensitivity of results, further work would be required to provide a proper assessment of the risks before proper decision could be made on this issue.

Table 18: Model parameters used to estimate expected benefits for discarding velvet crabs (from Mesquita, Dobby and McLay 2011).

	Parameter	Value	Units
Males			
	Growth – K	0.105	/year
	Growth - L(inf)	103	mm
	Natural mortality - M	0.1	/year
	Length/weight - a	0.0003	
	Length/weight - b	3.0389	
Mature Females			
	Growth – K	0.118	/year
	Growth - L(inf)	100	mm
	Natural mortality - M	0.1	/year
	Length/weight - a	0.0009	
	Length/weight - b	2.7405	
	t0	0	years

Table 19: Average price used for velvet crab commercial categories.

Category	Average Price (£)
Medium	1.96
Large	2.93
Extra-Large	3.60

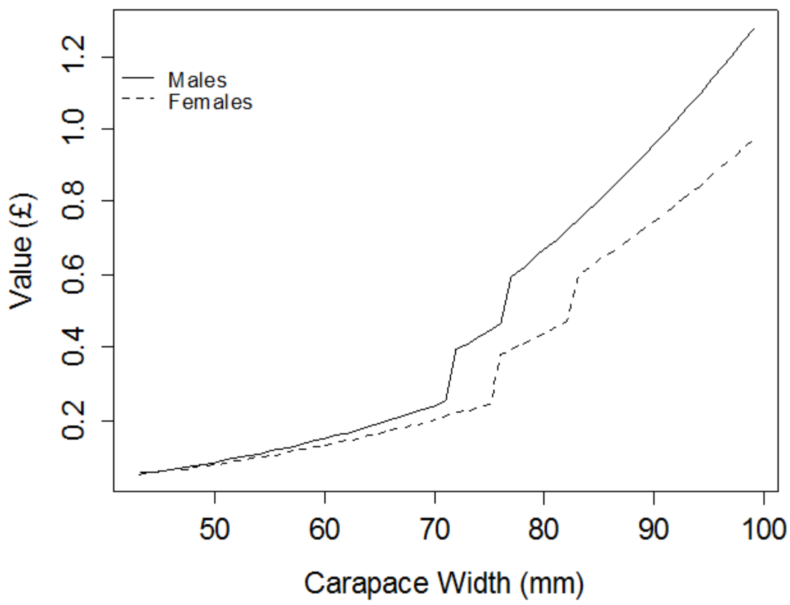

Figure 61: Individual crab value as a function of carapace width.

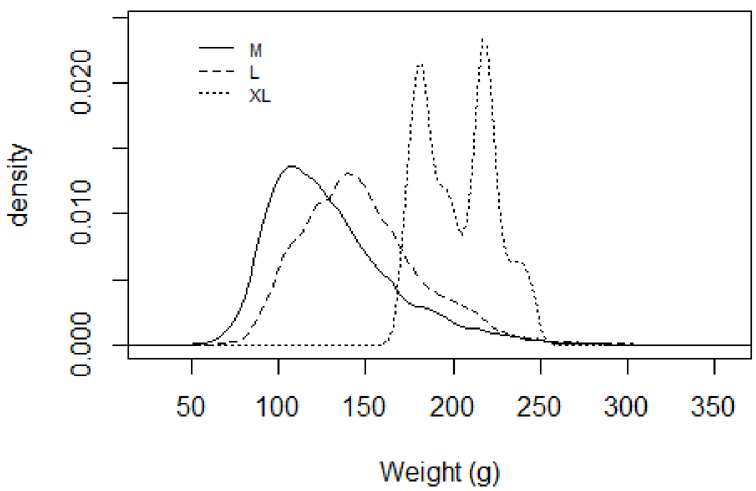

Figure 62: Smoothed weight size frequency for the three commercial size categories based on the size composition sampling. Weights are calculated from carapace width, so the bimodality for the XL category represents the difference in growth morphs for the two sexes.

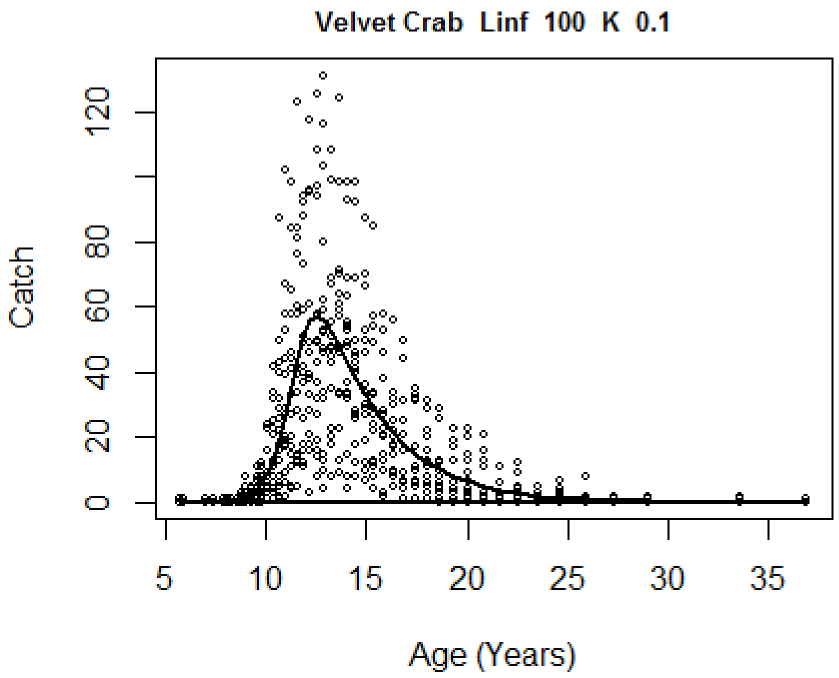

Figure 63: Observed (o) and expected (-) catch for the size composition samples based on the selectivity-mortality model.

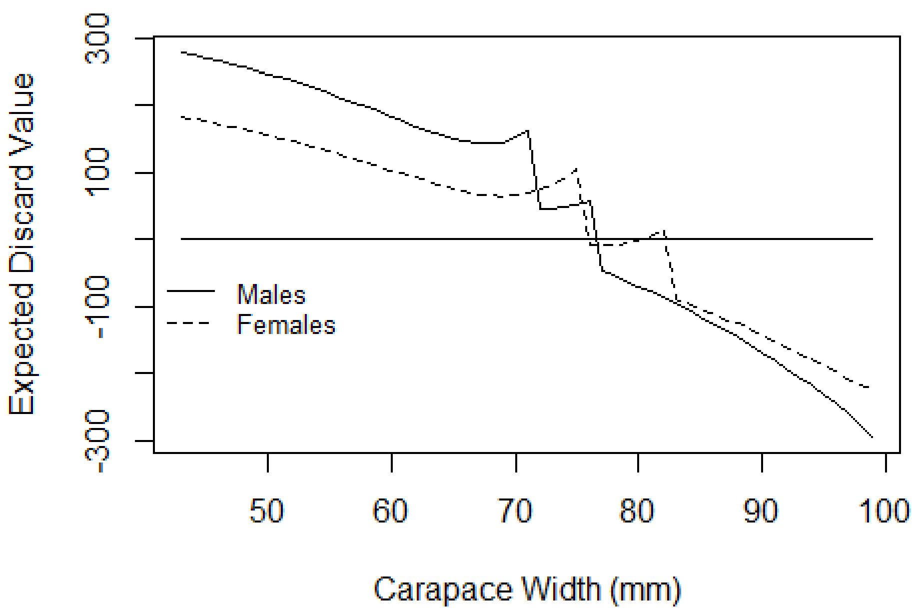

Figure 64: Expected discard value for individual velvet crabs based on carapace width.

13.8 Summary

YPR and UPR are simple calculations that capture major factors affecting changes in selectivity, growth and mortality, such as altering MLS or fishing mortality. These approaches are fairly inflexible and do not necessarily deal with dynamics or uncertainty well.

Decision theory is more flexible and able to combine a wide number of features and uncertainty integrating them into a single score. The method can hide complex calculations and critical assumptions however, which need to be carefully documented.

The results suggest that for *Nephrops* current harvest levels, trawl is unlikely to benefit from raising the minimum size unless capture can be avoided without any increase in mortality. Creels could benefit from a larger minimum size overall, which for males, would be retaining catches falling within the 40 or less count per kilo price category (more than 33mm CL). This also applies when considering both gears together. Likely decreases in catch rates from management interventions may offset any improvements in yield and value of the catch.

Similar results are obtained for velvet crabs. In this case, capture of carbs for the “medium” size category could be returned to the sea as recapture probability may be high. However, this may need further work to confirm as estimates natural mortality are highly variable.

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