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**Impact on the profitability of
the commercial UK Crangon
fishery**

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Impact on the profitability of the commercial UK Crangon fishery

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Abstract: As with many shrimp fisheries, the North Sea brown shrimp (*Crangon crangon*) fishery has been characterised by bycatch and discarding of juvenile fish species that are of value to other fleet segments. To offset this externality, the mandatory use of veil nets or separator panels was introduced in 2003 for all vessels using an aggregate beam length of more than 8m. Sea trials prior to this date suggested that retained catch may be reduced by between 8% and 35%, depending on the area and season. These studies, however, do not consider the behavioural response by fishers to reduce this impact. In this study, the actual impact of the restrictions on the productivity of UK *Crangon* vessels was estimated using a production frontier approach. The *ex post* analysis suggests a productivity decline of around 14% has been experienced by UK vessels adopting this gear.

Impact on the profitability of the commercial UK Crangon fishery

1. INTRODUCTION

Legislation requiring the use of technical measures in the EU *Crangon crangon* (brown shrimp) fisheries became effective from the 1st of January 2003. Foremost of these measures was the use of veil nets, the purpose of which was to reduce the associated bycatch of commercially significant juvenile fin-fish. This bycatch, if not caught by shrimp trawlers, would result in increased yields and profitability of the offshore whitefish fleet segments (Pascoe and Revill, 2004). Correcting the externality, however, is likely to reduce the productivity of the shrimp vessels, with resultant implications for their own profitability.

Field trials suggest that the use of the veil nets could result in a reduction in the retained catch of the targeted species (i.e. the brown shrimp) of between 8-12% (Revill and Holst, 2004). These trials, however, did not allow for potential change in behaviour of the fishers in response to the input control. Such a change in behaviour may reduce the impact of the measure on bycatch and discarding as well as on the level of retained catch. These effects can only be assessed by estimating the change in productivity retrospectively of the commercial fleet.

The purpose in this component of the study was to estimate the impact of the use of veil nets on the economic performance of the commercial fishing sector. Initially, information on changes in costs and earnings from a representative sample of vessels was to be collected, and an index number approach was to be used to separate out the impact of changes in productivity on profitability of the fleet. Unfortunately, only a small number of vessels were prepared to provide this information, too few to produce any meaningful analysis. As a result, the impact on productivity was estimated directly through a production function approach. Implications for changes in prices received are also examined.

The remainder of this study is structured as follows; the next section gives a brief overview of the North Sea and UK *Crangon* fisheries, section 3 considers the issue of bycatch and the impacts associated with it, section 4 looks at the anticipated economic effects of attempting to

tackle the bycatch issue, section 5 discusses the methodology, section 6 outlines the data used, section 7 describes how the models were specified and presents the results, and lastly section 8 discusses the analysis and conclusions we can draw from it.

2. THE UK EAST COAST CRANGON FISHERY

C. crangon is a non-quota species exploited by many of the countries that border the North Sea. Total annual North Sea landings have followed a fluctuating but upward trend since the 1970s and in 2006 total landings were over 37,000 tonnes, the highest to date. Germany and the Netherlands each land just under 44%, Denmark 11% with the remainder being attributed to the UK (around 2%) (ICES, 2006). The total value of landings can be estimated at circa £60 million (~ €91.3 million) if the average 2006 UK price of £1.63/kg is applied.

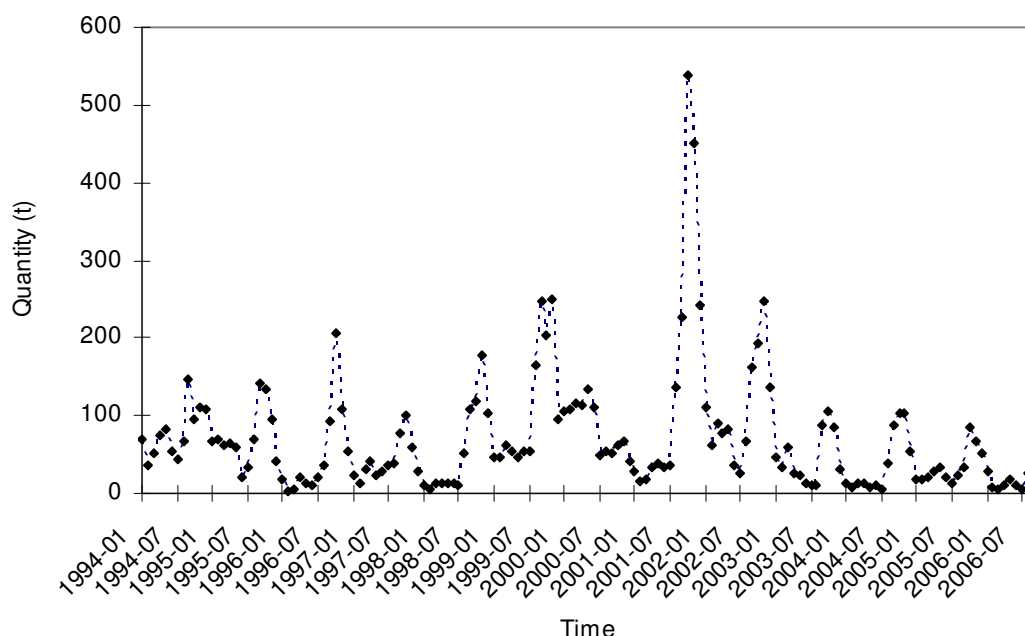
In 1998 there were over 600 vessels taking part in this fishery, approximately 16% of these were from the UK, (98 vessels) with the remaining 74% operating out of Germany and the Netherlands (Van Marlen et al, 1997). Generally twin rigged beam trawls are employed in the shallower coastal waters using cod ends with a minimum inside mesh size of 20mm.

The UK has *Crangon* fisheries on the East coast bordering the North Sea, in the Irish Sea into North Wales, Lancashire and Cumbria as well as artisanal fisheries elsewhere (usually not recorded). West coast landings are thought to generally be poorly recorded (A. Lawler 2006, pers. comm., December 05). By far the most significant of these is the North Sea (East coast) fishery, centred around The Wash. This fishery accounts for circa 90% of all recorded UK *Crangon* landings.

2.1 Effort and landings

The seasonal distribution of effort is highly variable and dependant on the abundance of *Crangon*, access to other potential target species and a number of other factors. The fishery operates year round but both effort and landings typically peak from September to November (Figure 1).

Figure 1. Monthly landings of *C. crangon* in the Wash
(source: CEFAS Shellfish Division).



Annual UK landings have tended to fluctuate over time, however, since reaching 1,865 tonnes in 2001 (~ £3 million first sale) they have followed a declining trend to around 500 tonnes per year in 2004 and 2005 (~ £700,000). Although total North Sea landings have tended to increase over the last decade, UK landings have tended to decline. Total landings in 2004 and 2005 are the lowest for the period observed. Lower prices and the increasing cost of fuel have been cited as significant factors associated with this decline (ICES, 2006). Biological factors would also be expected to be influencing landings. Stock assessments are not undertaken for *Crangon* so landings per unit of effort (LPUE) tend to be used in proxy¹. UK LPUE estimates also indicate a sharp decline over the period 2001 to 2003 and have remained at a relatively low level since, consistent with an apparent ‘sliding’ trend in North Sea *Crangon* fisheries towards the north-east. Environmental change has been cited as the possible reason for this (ICES, 2006), with the increased water temperatures in the southern half of the North Sea being less conducive to shrimp stocks.

¹ This is done by the ICES working group on *Crangon* fisheries and life history (WGCRAN), on the assumption that LPUE is directly proportional to stock size. For this proxy to be valid it must, amongst other things, satisfy the assumption of a linear catch/effort relationship and the measure of effort being reliable over time (i.e. it is not weakened via factors such as technological creep).

UK (East coast) *Crangon* vessels generally operate from the Humber Estuary down the Lincolnshire coast, in the inner Wash and around the North Norfolk coast (Figure 2). However, vessels may extend into deeper water (e.g. to the Docking shoal) in the winter and spring as water temperatures fall and the shrimp move offshore. ICES squares FO34 and FO35 are believed to be particularly important to the Wash vessels (ICES, 2005; 2006).

Figure 2. Main UK (East coast) Crangon ports and fishing grounds.

(Adapted from ICES, 2005; Revill, 1999)



Overall the annual level of effort applied to the fishery has declined noticeably since 2003 and estimates of total effort for 2004 and 2005 were lower than for previous years, a fact reflected in the landings (ICES, 2006).

2.2 Prices

Average annual UK prices have followed a relatively stable trend since 1999 fluctuating around £1.66 in real terms. Substantial seasonal variation is observed and tends to follow the pattern of effort and landings described above. Prices therefore tend to be lowest when effort peaks in September to November and highest in June/July when effort is often lowest. Whilst average annual prices have remained relatively stable looking at the monthly figures it can be seen since 2002 prices have not risen above £2.40/kg, despite a trend of falling landings.

The main end market for *Crangon* is mainland North Western Europe. Wholesale purchase of shrimp is dominated by one large buyer in the Netherlands and the vast majority of all UK (East coast) landings are sold in this way. The shrimp are sold through processors who grade and box the shrimp prior to its export. Previous work has suggested the law of one price exists (i.e. a single market) within the European brown shrimp market (Pascoe and Revill, 2004). Further, the price flexibility was estimated to be -1, which implies any change in *Crangon* landings would be matched by a proportional, and opposite, movement in price. This suggests a situation where fishers could potentially be compensated (in terms of revenue) should a reduction in efficiency and consequently landings be experienced.

However, as the UK's contribution to EU landings is relatively very small (~2 %) the amount they contribute to price changes may also be relatively minor. In this case prices would be more exogenously determined and any compensatory affect reliant on a similarly proportional reduction of landings at the EU level. A simple regression analysis² modelling UK price as a function of UK landings suggests that UK prices are highly inflexible with respect to UK landings, and that landings explain only a small proportion of the variation in prices (Table 1). From Table 1, a 10% decrease in UK landings is likely to result in only a 0.6-1% increase in UK price, so total revenue would decline. As the simple models explain only between 4% and 12% of the variation in price, prices can be effectively assumed to be exogenously determined.

Table 1. Relationship between landings and prices

	Levels ^a			First differences ^b		
	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
Intercept	0.816	0.093	8.812	-0.001	0.012	-0.102
Quantity	-0.063	0.023	-2.763	-0.097	0.021	-4.650
R ²	0.048			0.126		
Adjusted R ²	0.042			0.120		

a) $\ln P = \beta_0 + \beta_1 \ln Q$; b) $\Delta \ln P = \beta_0 + \beta_1 \Delta \ln Q$

Brown shrimp are graded by size (A-D) and this is reflected in the price they achieve. Information on price by grade is not generally available as only the total value of *Crangon*

² The models do not take into account other factors that may influence price such as changes in real income, landings of competing species and landings of shrimp in other countries. They also do not take into consideration factors such as dynamics in price adjustment and simultaneity bias. As a consequence, the results are indicative only and are provided to demonstrate the lack of relationship between UK landings and prices.

landings by trip is ultimately recorded by the Marine Fisheries Agency (MFA). For illustrative purposes we have derived an estimate of the average 2005 price by grade using observed landings, by grade, of three Wash vessels. Prices were £2.20, £2.03, £1.58 and £0.00 for grades A-D respectively (values inflated to 2006 equivalents). As the smallest grade (D) has little or no value there is limited incentive for fishermen to land these ‘fry’, they tend to be sorted out from the other shrimp and returned to the sea.

2.3 Regulation

The *Crangon* fisheries are managed under the European Common Fisheries Policy. Monitoring and enforcement is undertaken by the MFA,³ the Royal Navy’s Fishery Protection Squadron and local sea fisheries committees such as the Eastern Sea Fisheries Joint Committee (responsible for The Wash area fisheries).

Other than a commercial fishing licence as required by all UK fishing vessels there are no additional, fishery specific, entry restrictions. Furthermore, *Crangon* is a non-quota species and as such has no total allowable catch in place (TAC) to limit the overall volume of landings. There are two technical measures in place. One relates to allowable catch composition and specifies the target species (*Crangon*) must constitute a minimum of 60% of the catch when using a cod-end with mesh size 16-32mm (i.e. maximum bycatch of 40%).⁴ The other relates to the structure of the nets, which must include a sorting grid or ‘veil’ net.

As noted previously, the requirement to incorporate a veil net became effective from the 1st of January 2003. However, a number of EU (including UK) vessels are thought to have been using the technical measure prior to the year 2000.⁵ All but one of the other EU fleets (Belgium) are, however, thought to have had at least the same or if not a higher proportion of their effort using bycatch reduction devices making conditions for a compensatory affect unlikely.

³ Prior to October 2005 this was the responsibility of the Sea Fisheries Inspectorate of DEFRA.

⁴ Annex I of the COUNCIL REGULATION (EC) No 850/98 of 30 March 1998 for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms.

⁵ Proportion of effort thought to have been using bycatch reduction devices prior to 2000; Belgium 0.1, Denmark 1, France 0.5, Germany 0.6, Netherlands 0.4, UK 0.4 (Pascoe & Revill, 2004).

2.4 *Fleet/Vessel characteristics*

The UK (East coast) *Crangon* fishery has been a significant regional employer in the Wash ports of Boston and Kings Lynn, and to a lesser extent Grimsby. The most recent fleet inventory, undertaken in 1996, found there to be around 98 vessels operating from these ports (Revill, 1996). The size of the fleet is thought to have fallen since and it is currently estimated that up to 60 vessels are working or able to work in the wash fishery; approximately 40 from Kings Lynn, 12 from Boston and 6 from Grimsby. However, the number of vessels that could be considered as actively taking participating in the fishery at any one point in time is thought to be significantly lower than this. The majority of vessels targeting *Crangon* out of Kings Lynn and Grimsby are operated by one of four companies. In Kings Lynn, the number of private, skipper owned, vessels is believed to be on the decrease, exits (e.g. as a result of retirement or inconsistency of income) not being matched by entries. Boston is on the other hand predominated by smaller, skipper owned, vessels.

The fleet is somewhat heterogeneous in nature. Vessels range from 8 to over 18m in overall length and have engine powers of between 50 and 250kW. These boats typically fish twin beams, each 3.5 to 9m in length, using a 22-26mm inside cod end mesh size. However, the vast majority of this fleet are relatively multi-purpose and capable of targeting other species. Depending on their size the vessels may be crewed by up to 5 fishermen, however, it is believed that in recent years a combination of poor shrimp prices and increased fuel costs have led to these numbers being reduced wherever possible so a maximum crew of 3 is now more likely. Many of the under 10 meter vessels operate on a single-handed basis.

Catches are either landed on deck or into hoppers and sorted through riddles separating out saleable shrimp, non-saleable 'fry' and by-catch. The saleable shrimp is cooked on deck while the latter two fractions are discarded overboard at the point of sorting.

2.5 Other target species

The Wash also contains significant cockle and mussel fisheries (Figure 3) and if possible vessels will tend to exploit whichever is considered the most productive at that point in time⁶. Until recently, these fisheries appeared to be following a similar trend to that of *Crangon*. For example, cockle landings peaked in 2001 (8900 tonnes) and by 2005 was only open to hand working (503 tonnes landed) (data supplied by Eastern Sea Fisheries Joint Committee). However, a favourable stock survey led to the cockle fishery being re opened to dredging in 2006 and subsequently resulted in as few as three vessels pursuing shrimp from Kings Lynn in September/October 2006. The value of all three fisheries is plotted in Figure 3 and illustrates *Crangon*'s marked decline in both absolute and relative importance.

Figure 3. Value of landings for the three most important Wash fisheries 1994-2005, figures inflated to 2006 equivalents (ESFJC, 2005).



Lastly, certain vessels in the fleet possess licence entitling them to land fin-fish and as such have the option of targeting potentially high value species such as sole. These vessels also have the option of retaining and selling any marketable, incidental, by-catch (such as sole, skate or lobster) that may come about as a result of pursuing *Crangon*.

⁶ The Wash cockle and mussel fisheries are regulated and policed by the Eastern Sea Fisheries Joint Committee (ESFJC). Both fisheries are subject to a total (annual) allowable catch (TAC) based on annual stock surveys undertaken by the ESFJC, licences must be purchased in order to participate in these fisheries.

3. BYCATCH

As is the case with many commercial capture fisheries, and particularly shrimp fisheries (Alverston et al, 1994; Kelleher, 2005) there has been a significant by-catch and subsequent discarding of juvenile fin-fish associated with this fishery. This is primarily due to the small mesh size used and the fact that *Crangon* tend to occur in waters that are also nursery grounds for a number of commercially important fish species. The UK *Crangon* fleet was annually discarding an estimated 9.9 million plaice, 1.3 million sole, 12.9 million whiting and 4.6 million cod in 1996/7 (van Marlen et al, 1997). These discarded fish typically suffer from high rates of mortality as a result of their capture and the on-deck sorting process (Bergahn et al, 1992)

Whilst perhaps intuitively unpalatable to many it should not be assumed that discarding is always undesirable from the economic perspective. The discarding of low value fish can be socially optimal and occurs when the cost of landing the fish exceeds the value of the fish (as demonstrated by Arnason, 1994). However, the level of discarding observed in many fisheries is often above this social optimum and tends to result from either; the distortionary affect of management policies such as individual transferable quota (ITQs) (Anderson, 1994; Arnason, 1994); or situations where bycatch does not affect the cost of production of the individuals and as such is not self correcting. The externality may then be borne by fishers participating in associated fisheries, fish consumers or other groups in society that may experience a resultant reduction in utility (Pascoe, 1997). From the economic perspective this is a market failure, and the use of technical measures aims to correct for this by internalising these externalities.

Within the UK (East coast) *Crangon* fishery two factors led to the discarding of fish bycatch. First (and of primary concern), juvenile fish are under the required minimum landing size (MLS) and consequently have no present sale commercial value; second, the vessels licence may not give them entitlement to land fish bycatch. The bycatch and discarding associated with this fishery are consequently inefficient in the economic sense, a negative externality of the fishing process, often quantified by estimating the forgone value of potential future landings. Revill *et al* (1998) estimated UK (East coast) *Crangon* vessels were annually discarding cod, plaice, whiting and sole worth an estimated £2 million in lost landings. For the EU *Crangon* fishery as a whole mid range estimates of annual lost landings came to €25.7

million for the same four species (range 14-43.3) (Revill *et al*, 1999). Furthermore, discarding of commercially important species in the North Sea not only represents substantial foregone potential yield but for depleted stocks it can be considered a serious threat to biological recovery.⁷

EU concern over the level of discarding associated with *Crangon* fisheries and the potential affect this was having on the North Sea white-fish beam trawl fisheries led to a mandatory implementation of technical measures. The enactment of EU council regulation No.850/98 in 2000 required all beam trawlers participating in EU *Crangon* fisheries to have bycatch reduction measures in place by the 1st of January 2003, UK Shrimp Fishing Nets Order 2002.⁸ Specifically vessels fishing in English and Welsh waters are required to use nets fitted with either a selection grid or veil (sieve) net. This order regulates the use of fishing nets with mesh size between 16 and 31 millimetres and an aggregate beam length of over 8m.⁹ This statutory instrument was brought into force with the specific aim of significantly reducing juvenile fish by-catch.

Veils (sieves) are cone shaped nets fitted inside a standard shrimp trawl. These direct anything sufficiently large as to not pass through its mesh through an escape hole in the body of the trawl, allowing it to escape. Ease of handling and durability has tended to result in commercial fishermen choosing veils over the more cumbersome rigid selection grids. It is worth noting that as early as 1996 around 40% of the UK (East coast) fleet (by effort) were believed to be using veil (sieve) nets of 50-70mm mesh voluntarily (Revill, 1996). Additionally, a regulatory impact assessment (RIA) undertaken by the Department for Environment, Food and Rural Affairs (DEFRA) in November 2002 suggested that this figure was, by then, thought to be in excess of 80% (DEFRA, 2002).

⁷ The most recent ICES advice for North Sea Cod, Plaice and Sole suggest all are currently overexploited, with the Cod spawning stock below biological safe limits (ICES, 2006b).

⁸ Statutory instrument 2002 No.2870 (The Shrimp Fishing Net Order, 2002).

⁹ 'this does not apply if aggregate beam length is 8m or less; or a net headline of 8m or less.' The failure to specify *aggregate* headline length negates the majority of vessels from actually having to comply with the technical measure, their individual headlines generally falling short of 8m. This raises an interesting question with regard to enforceability.

4. ANTICIPATED IMPACTS TO INDUSTRY

In terms of additional costs imposed, the statutory measure is expected to have had three affects: first, the cost of purchasing, fitting and maintaining the veils; second, the potential loss of target species, escaping as a direct result of fitting the veils; and third, the loss to certain vessels of marketable, incidental, fish by-catch.

4.1 *Cost of purchase, fitting and maintenance*

The RIA estimated these costs were likely to be low. The cost of separator (sieve/veil) panels was expected to be minimal due to local sourcing and despite the panels taking up to a day to fit it was thought many fishermen were likely to do this themselves making an exact cost difficult to estimate, but again, this was expected to be small. Subsequent conversations with a number of fishermen have indicated opinions are somewhat mixed with regard to this point.

4.2 *Loss of target species*

It was anticipated the most significant economic effect of gear restrictions would result from an increase in the unit cost of harvest due to reduced catchability.¹⁰ A number of gear trials have been undertaken in the UK and reported potential losses of marketable shrimp to range between 8 and 21% (Graham 1998; Revill et al, 1998; Graham 2003; Revill and Holst 2004). Belgian trials have demonstrated the possibility of a seasonal effect. Using a commercial vessel and veil designs then used in the UK and Netherland commercial fisheries Polet et al (2004) showed loss of commercial catch to be between 8-19% in Spring/Summer and 28-35% in Autumn/Winter. This substantial winter loss coincides with the UK *Crangon* fisheries traditional period of highest activity and landings, a similar pattern of loss in the UK fleet would be severely detrimental. The higher winter losses were thought more likely to occur as a result of gilled fish causing a higher water flow through the outlet, taking some marketable catch with it.

The loss of marketable shrimp as a direct result of fitting veils is what concerned fishermen most. Under the assumption of 10-15% target species loss and 40% fleet of the fleet already

¹⁰ In the process of releasing non-target species bycatch reduction devices can also result in a certain proportion of the target-species circumventing the cod end.

having veils Revill et al (1998) estimated 100% uptake was likely to cost the whole UK (East coast) fishery around £300,000 per annum in lost landings. However, under an assumption of 5-8% target species loss used in the RIA, and 80% initial coverage the later RIA predicted losses would amount to, at most, £30,000 in total for fishermen in England and Wales (DEFRA, 2002).

4.3 *Loss of marketable non-target species*

A number of vessels were (and still are) licensed to land incidental by-catches of potentially valuable fish such as lemon sole, skate, brill and lobster. As such some fishermen on the east coast argued that a second cod-end should be allowed in the veil to retain these species. This was, however, rejected on the grounds it may impede the escape of immature fish, negating the effectiveness of this legislation.

Under the assumption effort is relatively free to move in and out of the fishery (and this is likely to hold in this instance), fishers will only participate in the fishery whilst marginal revenue is not exceeded by the marginal cost of taking part. Effort will, otherwise, be applied elsewhere. Previous studies (Revill et al, 1999; Pascoe and Revill, 2004) have predicted a net reduction in productivity for the UK *Crangon* fleet with reductions in both effort and catch per unit of effort (cpue) being expected. Within the Wash, it is likely any transfer of effort out of the *Crangon* fishery will primarily be into the cockle or mussel fisheries.

5. METHODOLOGY

The primary focus of this study is to consider whether the mandatory implementation of technical measures has had a negative economic impact upon the *Crangon* vessels/fleet. We base our *a priori* assumption of a neutral or non-positive economic effect on the reasons outlined above. From an economic perspective, any decline in profitability of the *Crangon* fleet is only efficient if it is less than gain in the profitability of the whitefish fishery as a result of removing/reducing the externality. The latter was established through the use of predictive bio-economic modelling in the pre-technical measure implementation project (Pascoe and Revill, 2004), provided that the assumed productivity effects were reasonably accurate.

The original productivity change estimates were based on gear trials at sea. This is a potentially artificial exercise, as it assumes that behaviour of the fishers will not change as a result of the use of the modified gear. Fishers might be expected to modify their behaviour in a way to reduce the impact of the new gear on their profitability. As a result, productivity changes may be less than estimated through sea trials. Conversely, productivity changes may be greater than estimated in the sea trial if fishers do not use the new gear effectively due to their unfamiliarity with the new gear. Thus, the impact on the commercial fishery is largely an empirical question, which can only be resolved by examining productivity changes that actually occur in the fleet.

The approach that was adopted to examine these productivity changes was the use of production frontiers. These estimate the relationship between catch and the use of inputs, and take into account differing levels of efficiency of the fishers. Changes in productivity as a result of the use of veil nets are estimated as a shift in the production frontier.

5.1 *Efficiency Estimation*

A mandatory technical measure is essentially a form of effort control. When effort controls are imposed on fishermen it is generally assumed the landings will be an attempt to maximise revenues under these constraints. Here we consider trip level revenue generation for the *Crangon* fishery and how this may have been affected by the shrimp nets fishing order.

Production functions use observed values to define the relationship between levels of input and the resultant levels of output (Schmidt, 1986). They indicate the average level of output as a function of a given level of input on the assumption that all producers are equally as efficient. Production frontiers differ in that they estimate the maximum level of output that can be produced from a given set of inputs, and consider deviations from this maximum level a result of inefficiency of the producers. The Battese and Coelli (1992) model is a stochastic frontier production function for unbalanced panel data which has firm effects assumed to be distributed as truncated normal random variables. This also allows the effects to vary systematically with time (Coelli, 1996) and may be expressed as:

$$\ln Y_{it} = x_{it}\beta + (V_{it} - U_{it}), \quad i = 1 \dots N, t = 1 \dots T$$

where $\ln Y_{it}$ is the production of firm i in time period t , x_{it} is a vector of explanatory variables, β a vector of unknown variables to be estimated, V_{it} the stochastic error term and U_{it} is the non-negative estimate of technical inefficiency of firm i . Both V_{it} and U_{it} are assumed to be independent and identically distributed (iid) with variance of σ_v^2 and σ_u^2 respectively.

There are a number of functional forms available for the production frontier. The translog functional form is popular and generally preferred over other functional forms as it is conceptually simple and imposes no *a priori* restrictions on elasticities of substitution, production elasticities and returns to scale. The general translog functional form can be expressed as;

$$\ln Y_{j,t} = \beta_0 + \sum_i \beta_i \ln X_{j,i,t} + \frac{1}{2} \sum_i \sum_k \beta_{i,k} \ln X_{j,i,t} \ln X_{j,k,t} - u_{j,t} + v_{j,t}$$

where Y is the landings of vessel j in period t and $X_{j,i,t}$ are the vessel inputs (i,k) to the production process. The error term is separated into two parts, $u_{j,i}$ is the estimate of technical inefficiency and $v_{i,j}$ is the stochastic error term.

The Cobb-Douglas is an alternate functional form and is effectively a special case of the translog where all $\beta_{i,k} = 0$. The Cobb-Douglas production frontier is estimated as:

$$\ln Y = \beta_0 + \sum_i \beta_i \ln X_{j,i,t} - u_{j,t} + v_{j,t}$$

Typically the translog form is estimated first and then its validity tested against that of the Cobb-Douglas specification. Implicit in the Cobb-Douglas production function is an elasticity of substitution of 1. Further, production elasticities are constant and identical for all producers.

5.2 *Estimating the impact of veil nets*

The impact of veil nets on the productivity of the vessels can be estimated through the use of dummy variables. These have a value of zero (0) or one (1), depending on the situation experienced at the time. The production frontier including the dummy variable can be given by

$$\ln Y_{j,t} = \beta_0 + \sum_i \beta_i \ln X_{j,i,t} + \frac{1}{2} \sum_i \sum_k \beta_{i,k} \ln X_{j,i,t} \ln X_{j,k,t} + \gamma D_{i,t} - u_{j,t} + v_{j,t}$$

where $D_{i,t}$ has a value of 1 if the vessel I was using a veil net in period t , or 0 otherwise. The dummy variable effectively shifts the production frontier up or down. Implicit in this formulation of the model is that the proportional impact of the veil nets is identical for all vessels.

6. DATA

6.1 *Catch and effort data*

Vessel logbook data detailing *Crangon* landings by individual trip for 56 vessels over the period January 1999 to August 2006 were obtained from the CEFAS Fisheries Activity Database (FAD). In addition to weight (Kg) and value (£) each individual observation contained information relating to; vessel and gear characteristics, effort, and other temporal and spatial aspects of the trip and fishing operation. The initial dataset consisted of 11,243 observations specifically related to landings of *Crangon* as a result of beam trawling. A cost and earnings survey was also undertaken, however, the data this yielded were ultimately insufficient to allow any meaningful additional analysis.

Information on each tow was available, enabling an estimate of total fishing time per trip as well as time at sea. As with any dataset, data entry errors are likely to exist. As a result, spurious observations were removed. These include those where recorded hours fishing

exceeded that possible for the length of trip, the length of trip exceeded 96 hours,¹¹ and the implicit price (i.e. value/quantity) exceeded £6/Kg or was less than £0.50/Kg. This resulted in an unbalanced panel dataset consisting of 9988 observations for 51 vessels, each relating to a singular discrete fishing trip. These observations were then aggregated to the monthly level resulting in 1682 observations over a period of 92 months.

A direct assessment of the veils impact is somewhat complicated by the fact a number of vessels are believed to have been using them for some years prior to it being mandated. Records on the exact point in time at which a vessel took up veils do not exist and even where an estimated ‘date of first use’ can be hazarded at, their use from that point up to the 1st of Jan 2003 cannot be assumed as continual. Having the veil dummy start predominantly from January 2003, when the regulation came into force, imposes an assumption that is unlikely to bear universal resemblance to reality. More likely is a period of uptake and adjustment prior to enforcement, a scenario supported by the belief up to 80% of effort was using veils prior to the end of 2002 (DEFRA, 2002).¹² Given this uncertainty relating to the point of uptake, and the increased likelihood of measurement error during this period, observations for the years 2000-01 and 2001-02 were excluded. The final dataset was therefore discontinuous, consisting of 1156 monthly observations for 51 vessels (Table 2).

Table 2. Descriptive statistics for observed Crangon landings, 1999-06, at the month level for 51 vessels.

	Min	Max	Mean	SD	Asymptotic test: χ^2	Normality test: χ^2
<i>All data (1682 obs.)</i>						
Landings (kg)	7.00	50552.00	2313.60	3530.50	104840**	5657.20**
Revenue (£)	10.03	84592.00	4043.50	5667.20	112930**	4019.90**
Kw	59.00	224.00	149.54	55.63	146.85**	316.34**
Effort (h)	1.00	240.00	63.00	46.73	264.71**	486.75**
<i>Excluding 2000-01, 2000-02 (1156 obs.)</i>						
Landings (kg)	7.00	17366.00	1979.40	2516.70	3631.20**	2182.60**
Revenue (£)	10.03	27607.00	3359.40	4111.30	2916.60**	1945.90**
Kw	59.00	224.00	152.18	54.83	96.76**	211.77**
Effort (h)	1.00	220.50	60.93	46.11	183.92**	363.02**

* indicates significance at 5%, ** sig. at 1%

¹¹ Realistic extremes for trip length and price of shrimp were determined based on conversations with vessel skippers.

¹² Further analysis of the data further supported this with high variability being observed in the (all vessel) monthly CPUEs standard deviation for a period prior to late 2002, before and after this point a more stable pattern was observed.

All variables were subsequently logged and normalised to a mean of zero. This is done to ensure the production technology is appropriately estimated, the translog specification of the revenue function only being valid under such conditions. Furthermore, the coefficients on the variable levels directly represent their elasticities making interpretation more straightforward.

6.2 *Treatment of stock*

An important factor affecting the catch of any vessel is the level of stock. As data relating to *Crangon* stock biomass do not exist, an alternative measure was required. A proxy measure for stock used in the scientific assessment is the landings per unit of effort (LPUE). However, the use of LPUE at a fleet level was not appropriate in this instance. This measure would have picked up and incorporated any observable effect on efficiency the gear change may have had with the change in catchability assumed to result from fluctuations in the stock level. Changes in the fleet composition and technical change also affect the average LPUE, even if stocks are unchanged (Pascoe and Herrero, 2004).

A stock index measure was subsequently derived in proxy based on the geometric mean of 6 individual vessels monthly LPUE indices. These were vessels believed to have been consistently using veils prior to the start of the data set and, as such, represented a constant in that respect. LPUE (kg/hr) was generated using total (live) weight of landings/hours fished by a vessel each month. This was based in December 2001 (a month where all six vessels were active in the fishery). Under the assumption changes in LPUE over time are symptomatic of changes stock size this value can then be directly incorporated into a translog function (as seen in Kirkley et al, 1995; 1998).

LPUE has a number of theoretical problems as a stock index as well as practical problems due to changes in fleet composition and technical change. A significant weakness of this approach is the implicit assumption of constant returns to effort and stock (Pascoe and Herrero, 2004). Within fisheries, constant returns to either are generally unrealistic assumptions. Alvarez (2003) has also demonstrated that the use of LPUE as a stock proxy can result in biased parameter estimates, even if the constant returns to scale conditions are met.

An alternative approach to using the LPUE index to represent stock is to use dummy variables to represent the year and month effects. While this overcomes both concerns raised above,

incorporating a dummy variable for every year and month separately is impractical, whereas incorporating a monthly dummy variable (i.e. January-December) assumes a constant seasonal pattern that does not change from year to year. The year was defined as running from July to June, as this tended to result in the most consistent seasonal pattern, and is consistent with the assumption that *Crangon* recruit to the fishery in July and then grow on (ICES, 2005).

As both approaches have limitations, both were incorporated into the analysis so that the results can be compared, and any consistencies identified.

6.3 *Cost data*

A cost and earnings survey was undertaken with questionnaires being distributed via local fisheries officers to vessels in Kings Lynn and Boston. This was followed up with a number of visits to the ports where skippers were interviewed on a face to face basis. Overall willingness to participate was poor or records insufficiently detailed to be of any use.¹³ Information on fixed costs were obtained for vessels from two of the three large companies in Kings Lynn and more comprehensive information collected for three private vessels. The collection of information relating to vessel fuel consumption (and price paid) over time was found to be especially problematic, all but one of the vessels that data was obtained for did not have any record of this and often the best skippers could do was estimate current consumption in litres per trip.

7. MODEL ESTIMATION AND RESULTS

7.1 *Model specification*

The translog production frontiers were initially specified as follows;

¹³ Information on individual fixed costs for many ‘company’ vessels was often incomplete at the vessel level and in the case of variable costs absent. A significant issue was the fact in certain instances fleets were effectively run as one vessel (and were not even all shrimp vessels), inputs such as fuel and fishing gear were often purchased in bulk and their subsequent use not recorded by vessel.

$$\ln Y_{it} = \beta_0 + \beta_1 \ln x_{KWit} + \beta_2 \ln x_{EFFORTit} + \beta_3 \ln x_{STOCKt} + \beta_4 \ln^2 x_{KWit} + \beta_5 \ln^2 x_{EFFORTit} + \beta_6 \ln^2 x_{STOCKt} + \beta_7 \ln x_{KWit} \ln x_{EFFORTit} + \beta_8 \ln x_{KWit} \ln x_{STOCKt} + \beta_9 \ln x_{EFFORTit} \ln x_{STOCKt} + \gamma D_{it} + (V_{it} - U_{it})$$

for the stock-based model, and

$$\ln Y_{it} = \beta_0 + \beta_1 \ln x_{KWit} + \beta_2 \ln x_{EFFORTit} + \beta_3 \ln^2 x_{KWit} + \beta_4 \ln^2 x_{EFFORTit} + \beta_5 \ln x_{KWit} \ln x_{EFFORTit} + \sum_{m=2}^{11} \mu M_m + \sum_{y=2}^8 \omega A_y + \gamma D_{it} + (V_{it} - U_{it})$$

for the dummy variable based model, where Y_{it} is the live weight of landings for vessel i in time period t , x_{KWit} engine power in Kw, $x_{EFFORTit}$ is effort (hours fishing), x_{STOCKt} the constructed stock (LPUE) index variable, M_m is a set of dummy variables representing each month of the year, A_y is a set of dummy variable representing each year and D a dummy variable included to pick up the effect of mandatory veil use (assigned a value of 0 prior to Jan 1st 2003 and 1 after).¹⁴ When using dummy variables to represent seasonal patterns or changes over time, one month or year must be excluded as the base to avoid problems of collinearity. This is implicitly captured in the constant term of the model. In this case, July and 1998-99 were used as the base periods.

A priori, all coefficients other than the veil dummy are expected to be positive. For reasons discussed above, if significant, the veil coefficient is anticipated to be negative.

Empirical results

The analysis was performed using FRONTIER 4.1 (Coelli, 1996) where various choices can be made in relation to the models functional form and inefficiency distribution. We initially assumed the more general truncated normal distribution for the inefficiency effects ($\mu \neq 0$). All models were restricted to the time-invariant efficiencies form ($\eta = 0$) due to data discontinuity. Alternative models were then estimated and the best selected using the

¹⁴ There were some exceptions to this rule. The dummy was set to equal either one (or zero) for the small number of vessels known to have been consistently using (or not using) veils for the data's duration.

likelihood ratio tests, $LR = -2\{\ln[L(H_0)] - \ln[L(H_1)]\}$ where $\ln[L(H_0)]$ and $\ln[L(H_1)]$ represent the values of the null and alternative hypothesis, respectively.

The initial choice of a translog functional form was tested against a Cobb-Douglas specification for both the index and dummy models (Table 3). The alternative form was rejected when using a stock index, validating the translog choice. The Cobb-Douglas specification could not, however, be rejected when incorporating a stock dummy resulting in the Cobb-Douglas specification being accepted as most appropriate. The distributional assumptions were then tested and in both cases the half-normal assumption strongly accepted. The half-normal ‘translog index’ and ‘Cobb-Douglas dummy’ specifications were then tested for the existence of a frontier. Both rejected the $H_0: \gamma = 0, \sigma_u^2$ equals zero and therefore no inefficiency exists, at the 1% level using the appropriate tables derived by Kodde and Palm (1986).

Table 3. Specification tests

Null Hypothesis H_0 :	$L(H_0)$	$L(H_1)$	λ^a	Deg. freedom	Sig.	Decision
Using stock index						
$\beta_{i,k} = 0$	-788.743	-760.837	55.81	7	0.00%	reject H_0
$\mu = 0$	-760.976	-760.837	0.28	2	87.03%	accept H_0
$\gamma = 0$	-873.65	-760.976	225.35	1	0.00% ^a	reject H_0
Using dummy variables						
$\beta_{i,k} = 0$	-788.704	-785.096	7.21	4	12.50%	accept H_0
$\mu = 0$	-788.920	-788.704	0.43	2	80.52%	accept H_0
$\gamma = 0$	-902.18	-788.920	226.52	1	0.00% ^a	reject H_0

^a $\lambda = -2[\ln\{L(H_0)\} - \ln\{L(H_1)\}]$, ^b Using critical value of Kodde and Palm (1986)

The resultant production frontiers are presented in Table 4. In both models, the elasticity associated with engine power is around 0.3, suggesting that a 10% increase in engine power would only be expected to increase output by 3%, all other things being equal.

In the model using the LPUE as the stock proxy, the effort elasticity was significantly different to 1. As an assumption of the use of the LPUE index is that there is a linear relationship between catch and effort, the results of the model are not internally consistent. The “stock” coefficient in the LPUE based model is also significant but estimated at around 0.66. Again, this should be nearer to 1 if the assumption of LPUE being proportional to stock

size is to hold (Alvares, 2003). It indicates the stock proxy variable is likely to be biased and as such unreliable.

Table 4. Parameter estimates for the alternative models.

LPUE proxy			Dummy variables		
	coefficient	t-ratio		coefficient	t-ratio
constant	0.733	8.706 ***	constant	0.286	2.830 ***
ln kW	0.300	3.416 ***	ln kW	0.332	3.956 ***
ln effort	1.082	53.899 ***	ln effort	1.023	60.357 ***
ln stock	0.662	21.450 ***	veil dummy	-0.146	-2.632 ***
ln kW ²	-0.895	-3.124 ***	1999-00	0.545	7.236 ***
ln effort ²	0.024	1.860 *	2002-03	-0.256	-3.248 ***
ln stock ²	0.045	1.166	2003-04	-0.620	-6.817 ***
ln kW * ln effort	-0.053	-1.297	2004-05	-0.216	-2.371 **
ln kW * ln stock	0.344	6.143 ***	2005-06	-0.293	-3.087 ***
ln effort * ln stock	0.021	0.830	2006-07	0.446	1.965 **
veil dummy	-0.255	-6.749 ***	August	0.383	4.707 ***
			September	0.754	9.549 ***
			October	0.866	11.203 ***
			November	0.719	9.363 ***
			December	0.537	6.886 ***
			January	0.315	4.029 ***
			February	-0.013	-0.159
			March	-0.063	-0.796
			April	0.170	2.115 **
			May	0.093	1.165
			June	0.008	0.096
σ^2	0.521	6.057 ***	σ^2	0.506	6.596 ***
γ	0.620	9.576 ***	γ	0.588	9.187 ***
log likelihood	-760.976		log likelihood	-788.920	

* indicates significance at 10%, ** sig. at 5%, *** sig. at 1%

The impact of introducing veil nets on the productivity of the fishers can be derived from the coefficient related to the veil dummy. In the case of the model using the LPUE index to represent the stock, the use of a veil net is estimated to reduce productivity by $(1 - e^{-0.255}) * 100 = -22.46\%$. For the model using the dummy variables, the impact is estimated to be $(1 - e^{-0.146}) * 100 = -13.58\%$. Given the inconsistencies in the model as well as the theoretical problems associated with the use of LPUE as a stock proxy, it is likely that the variable using monthly and annual dummy variables is more reliable. Further, the productivity effect of a decline in catches of around 14% is consistent with the sea trial results.

8. DISCUSSION AND CONCLUSIONS

This study assesses the affect mandatory uptake of bycatch mitigating technology has had on the output of a sample of the UK *Crangon* beam fleet. Two stochastic production models were developed, one using a LPUE index to account for changes in the *Crangon* stock, and one utilising seasonal and annual dummy variables. In both cases a significant and negative effect on output is determined to have arisen, this being estimated at 22.5 and 13.6% for the different models, respectively. Both lie within the range of directly observed marketable shrimp losses reported in the previously discussed sea trials.

A lack of information on the date individual vessels started regularly using the technical measure means both models potentially underestimate its full effect. An implicit assumption of the veil dummy becoming active on the 1st of January 2003 is that these vessels were not using the measure prior to this point, where this assumption is not satisfied the true ‘veil effect’ will become diluted. In an attempt to minimise this effect data in the period prior to use becoming mandatory, where a significant number of vessels are suspected to have been using veils essentially unobserved, were removed. Furthermore, in the small number of instances where a reliable date of uptake was known the dummy for this vessel was adjusted accordingly.

The first ‘stock index’ model additionally suffers from the problem of the coefficient on effort being significantly different to 1. LPUE is, therefore, not proportional to stock¹⁵ and the potential for bias in the results exists. The second model circumvents this issue through the use of dummy variables and is consequently considered more reliable. Furthermore, additional anecdotal evidence indicates average loss estimates as high as 22.5% may be overstating the veils affect. It has been reported losses around this level are unacceptably high and (given the choice) would result in fishermen not using the device (Revill and Holst, 2004). The fact a number of vessels were using veils voluntarily for some time prior to use being mandated indicates any associated loss cannot have been considered unacceptably high. This suggests skippers were either naive as to the veils true affect, unconcerned by such a

¹⁵ For LPUE to be a reliable stock proxy the coefficient must be close to one where the assumption catch (y) is a function of fishing effort (E) and stock (S), $y = qES$, is being made (the catchability coefficient, q , is assumed to be constant).

high level of loss or losses were not as high, in reality, as the index model suggests. The first two scenarios are considered unlikely.

Fisher opinions relating to the technical measure are somewhat varied. A number of skippers from the port of Boston indicated a reluctance to fish for shrimp in the last few years, especially those vessels that only occasionally took part in the fishery. Increases in the price of fuel, poor shrimp prices and the additional time/impracticality of using veils were all cited as contributory factors. The number of vessels annually taking part in the fishery from both Boston and Kings Lynn appears to have been relatively stable for the period between 2000 and 2005, however, total hours at sea by vessels from these ports has declined.

The complaint that veils can become fouled by weed and hydroids, effectively preventing the passage of catch into the cod-end and determined as a cause of poor performance in some hauls by Polet et al (2004) was a complaint echoed by fishers in The Wash area. Additional costs are incurred in terms of lost landings and fishing time when this happens. However, the majority of skippers spoken to indicated a general preference for veils, so long as the gear is rigged and fished appropriately. These fishers primarily targeted *Crangon* and have spent time tuning their gear in an attempt to maximise its productivity. Most also stated that given the choice they would now rather not fish without them. A number of initially unanticipated benefits were also suggested; When not using veils weed that collects in the cod end also leads to sand being collected and has a negative affect on the quality of any shrimp; They reduces the amount of crab in the cod-end and the damage these do to the shrimp; Veils can reduce the time spent sorting out by-catch not such an issue on larger boats that use rotary sorters but perhaps more significant to single handed vessels; Gear-trial surveys suggest a potentially significant reduction in the retention of fry (28-65% Polet et al, 2004), possibly due to better sorting in the cod-end, again reducing sorting time on deck and is presumably only beneficial to the *Ccrangon* stock level.

It appears veils require some time investment by fishers in order for them to fish productively, minimising target species loss. Fishers that tend to dip in and out of the fishery are less likely to make the necessary investment resulting in what is already an apparently relatively unattractive fishery to some (for reason of fuel and shrimp price cited above) even less so. A prominent shrimp fisherman from one Wash port believed using veils is prohibitively costly in terms of the time spent clearing them and the difficulty of hauling them aboard when

heavily fouled, nets needing to be either turned inside out and/or towed through the water to remove the weed. It was stated that on anticipation of heavy weed vessels may simply disable their veils. Apparently relatively easy and quick to do as the bottom of the veil can simply be detached allowing everything going into the mouth of the net to flow through to the cod-end, raising some questions with regard to the level of compliance. Another negative point raised was the additional expense associated with fitting veils. There are a limited number of people with the ability to rig veils, they are hard to set correctly and this is important if they are to fish well. If the veil is set too tight catch can be directed out of the bottom of the net. It was suggested that perhaps only two individuals in Boston were capable of doing this for themselves. Nets can be bought from Holland but are more expensive than those without veils.

A lack of reliable cost data made further assessment, considering profitability in addition to productivity, unfeasible. Many of the skippers approached were willing to cooperate in principal but claimed to be either physically unable to provide the information at the level required (for example historical fuel consumption/costs) or ultimately did not have the time/inclination to go back through their records. The general dearth of accessible records on basic cost data within fisheries research is problematic and likely to persist until vessels regularly report basic information on things such as fuel quantities and other variable costs along side that currently required by their log books. It is only by reporting these data as a matter of course that reliable datasets, allowing rigorous economic analysis and subsequent management, will be constructed.

We can conclude that, in general, veil efficiency is likely to vary significantly depending on the fisher using them and prevailing environmental conditions. Considering the anecdotal evidence it appears reductions in productivity will have been felt strongest by vessels that do not primarily target shrimp. The model incorporating dummy variables is considered the most reliable and indicates a marketable shrimp loss value analogous to those seen in field trials. However, and on average, whilst a measurably significant reduction in output is believed to have occurred as a result of using veils, this is not thought to have not occurred at the sort of level previously reported as being economically unacceptable to fishers.

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