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A Bioeconomic Analysis of the Swedish Fishery for Norway Lobster (*Nephrops norvegicus*)

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Abstract *A modified version of Jones' length-based cohort analysis is linked to economic data from the Swedish trawl fishery for Norway lobster (*Nephrops norvegicus*). The current regulation implies a fishing practice where each landed lobster entails three killed due to discard mortality, and different cases of trawl selectivity are compared together with varying natural mortality. The bioeconomic analysis shows that a maximum economic yield equilibrium requires effort reductions of more than 50%, leading to a potential resource rent of almost US$3 million, compared to the open-access situation in 1995. Further increase of the resource rent is possible if a more selective trawl is introduced and enforced. The trawl fishery is compared with a minor in-shore creel fishery, which differs in exploitation pattern, fuel consumption, and impact on the benthic flora and fauna. A qualitative discussion on the two fisheries is carried out and a comparison of the economic performance is presented.*

Key words *Bioeconomics, fisheries economics, Norway lobster, Sweden*

Introduction

The Norway lobster (*Nephrops norvegicus* Linneaus, 1758), sometimes referred to as Dublin Bay prawn, is landed in several European countries. In 1995, the ICES working group on *Nephrops* stock assessment (Anon. 1997) reported eighteen management areas (major stocks), exploited by fishers from fourteen countries. Total landings were about 50,000 tons, amounting to a value of roughly US$200 million. This implies that *Nephrops* is the most valuable crustacean landed in Europe. The two principle gears in use are bottom trawls and creels (pots, traps). Trawl landings account for more than 95% of landings. A common feature of most of the areas where *Nephrops* is exploited is that creels are used in an in-shore fishery, while trawlers operate offshore. In general, trawlers displace creel fishers from shared grounds because creel fishers cannot afford the risk of their gears being destroyed by trawlers. Changing the boundary of where trawling is allowed creates potential conflict and is of concern to fisheries managers. The two modes of fishing differ in exploitation pattern, fuel consumption, and probably differ in their impact on the benthic communities. The growing awareness of potential damage to the benthic

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flora and fauna from repeated bottom trawling has reinforced the discussion on where to place the trawling boundary. In the Faeroe Islands, for example, a complete ban on trawling in inshore areas was imposed in 1980 (Anon. 1990).

Three countries share the Scandinavian stock of *Nephrops*, which is assumed to be one stock distributed in both the Skagerrak and the Kattegat (figure 1). Annual landings during the 1990s were roughly 3,500 tons corresponding to a value of about US$25 million.[1] Danish fishers take about 70%, Swedes almost 30%, while Norwegian landings amount to only a small percentage of the total landings. A Total Allowable Catch (TAC) of 3,500 tons was agreed upon in 1992, and this was increased to 4,800 tons in 1995. However, the TAC has not been binding (figure 2).

The concern of this study is the Swedish commercial Norway lobster fishery, where 80% of the landings is taken by *Nephrops* trawlers, 15% by creel fishers, and the rest is landed as bycatch by fish and shrimp trawlers. Until the mid-1980s, *Nephrops* were caught solely by trawlers, but at that time a coastal creel fishery evolved, due in part to the existence of unexploited *Nephrops* grounds inside the trawling border, the experiences from profitable creel fisheries around Scotland, and an increase in the real price for *Nephrops*. In 1984, before the creel fishery had achieved any economic significance, the trawl border was moved closer to shore. As the Swedish creel fishery developed into a minor but stable fishery, and due to the concern of environmental effects, the discussion on where to place the Swedish trawling boundary has been revived.

The purpose of this study is twofold. The first is to apply a bioeconomic model to empirical data from the trawl fishery to estimate the optimal effort level. For this objective, a modified version of Jones' length-based cohort model is linked to a net revenue function (Jones 1984). The second is to compare the two fisheries in terms of qualitative aspects, as well as economic performance.

The Norway Lobster Fishery in Kattegat and Skagerrak

The Swedish trawl fishery for *Nephrops* landed 366 tons in 1978, gradually increasing to 1,024 tons in 1984. During the period 1984–91, the landings were stable despite a doubling of trawling effort, which implies a significant reduction of the full-sized portion of the stock. The period of high landings was followed by some years of reduction, and in 1995, landings were 803 tons (figure 2).

Despite the fact that landings were stable during the period 1984–91, effort continuously increased, likely due to an increase in nominal prices (figure 3). During 1989–92, twin trawls were introduced, which also led to larger standard effort figures. The landings per unit of effort (LPUE) ratio between twin and single trawls is constant at about 1.7, and the effort figures in figure 2 are standardized and adjusted to single trawl effort. The latter implies that the effort figures in terms of number of vessels can be adjusted downward for the period 1989–95. The reduction of effort in 1994–95 is, in terms of vessels, even more drastic and a likely result of *inter alia* the reduction in price and shift of effort to the more profitable shrimp fishery for the same period.

Commercial creel fishery for *Nephrops* has taken place in coastal Scottish waters for more than thirty years. Using the Scottish experience, a creel fishery evolved in the mid-1980s in Sweden. Because trawlers are banned within the archipelago, this resulted in exploitation of virgin areas leading to profitable landings with a large quantity of big and valuable lobsters. Entry to the fishery is free, but

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[1] $1 = 8 SEK

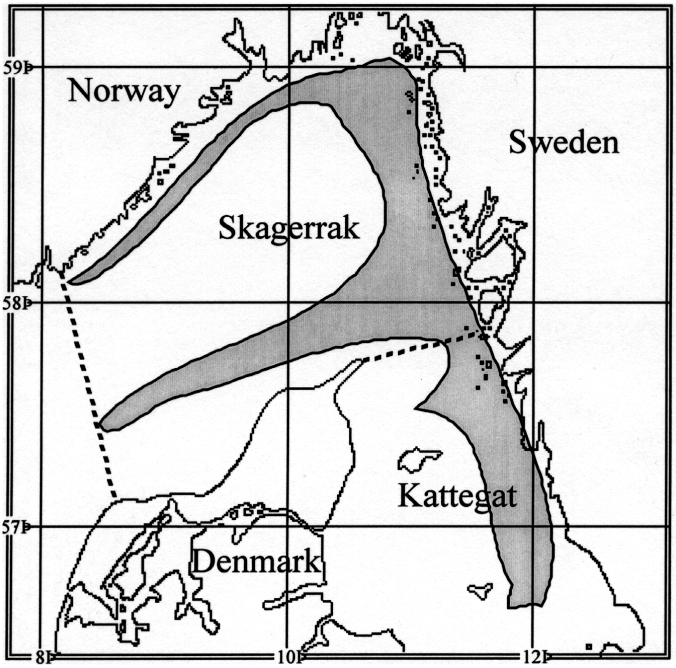

Figure 1. *Nephrops* Grounds (shaded) in Skagerrak and Kattegat

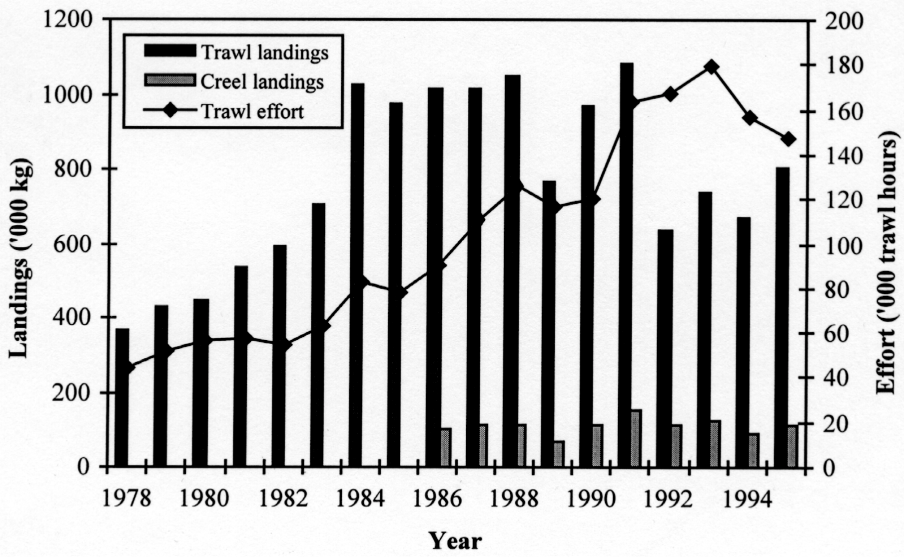

Figure 2. Landings and Effort of the Swedish *Nephrops* Fishery
Source: 1978–95 (log book data)

landings have been fairly stable, at roughly 100,000 kg during the 1990s. By 1995, the number of creel vessels had stabilized at approximately 40. A few vessels have two crew members, but most have a single fisher.

The population dynamics of *Nephrops* are not perfectly known, and stock assessments are uncertain. Yet, time series on overall landings per unit trawl standard effort from Skagerrak/Kattegat logbook data show a drastic reduction in landings, from 10–12 kg/hour in the early 1980s, down to 3–4 kg/hour during 1992–93 (figure 4).

During the same period, annual trawling effort increased by about 200%. During 1994 and 1995, the LPUE increased, which seems to contradict the previously noted stock reduction. Two possible explanations are a trend in recruitment and heterogeneity in the fishing fleet. A trend in recruitment violates the crucial assumption of constant recruitment for length cohort analysis (LCA). Our data does not allow for identification of a trend in recruitment. The yearly length frequency distribution in figure 5 might be interpreted to suggest that there were slightly higher recruitments to catchable sizes in years 1993–94. Concerning the fishing fleet, it is possible that the years of declining LPUE led to an exit of fishers. If the remaining fishers are more skilled, they could have a higher LPUE, despite the stock reduction. Unfortunately, our data does not provide any possibility for judgement between these alternate explanations.

Regular measurements on size compositions from the Scandinavian commercial trawlers in Skagerrak/Kattegat show that 78% of the catch (in numbers) is undersized and discarded (Anon. 1997). The discard mortality from trawl fishery is approximately 75%, which means that for every landed *Nephrops*, almost three die (Anon. 1998). In fact, this figure is even higher, as 10% of the escapees die due to gear inflicted injuries, leading to about three and one-half dead for every landed lobster (*ibid.*). The figures for the Swedish trawl fishery are almost as alarming. The fraction of undersized *Nephrops* amounts to about 55%. The high incidental mortality in addition to a probable stock reduction implies that the present harvest strategy

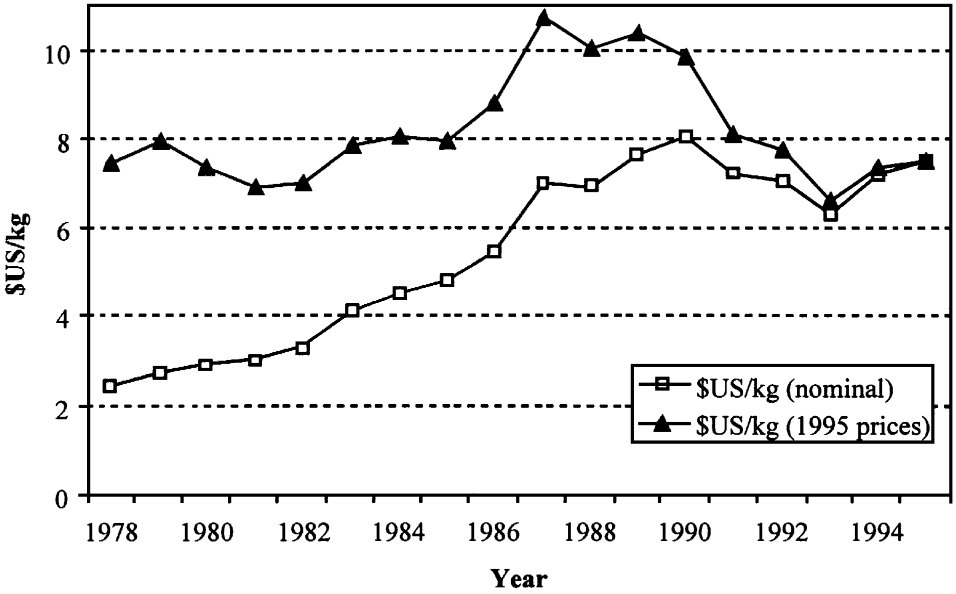

Figure 3. Ex-Vessel Prices for *Nephrops* (nominal and 1995 prices) 1978–95
Source: Statistics Sweden

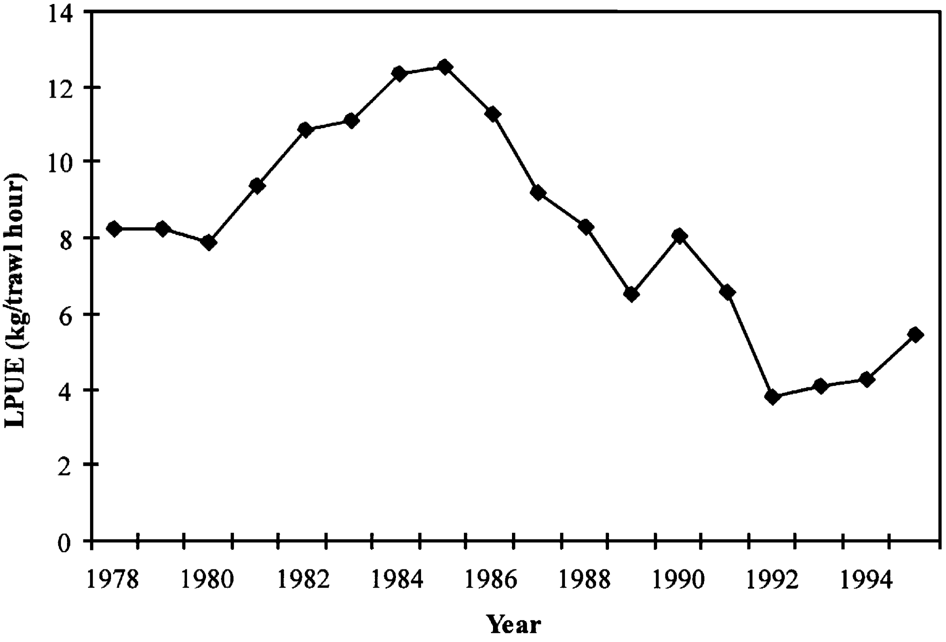

Figure 4. Landings Per Unit Single Trawl Effort (kg/hr) 1978–95

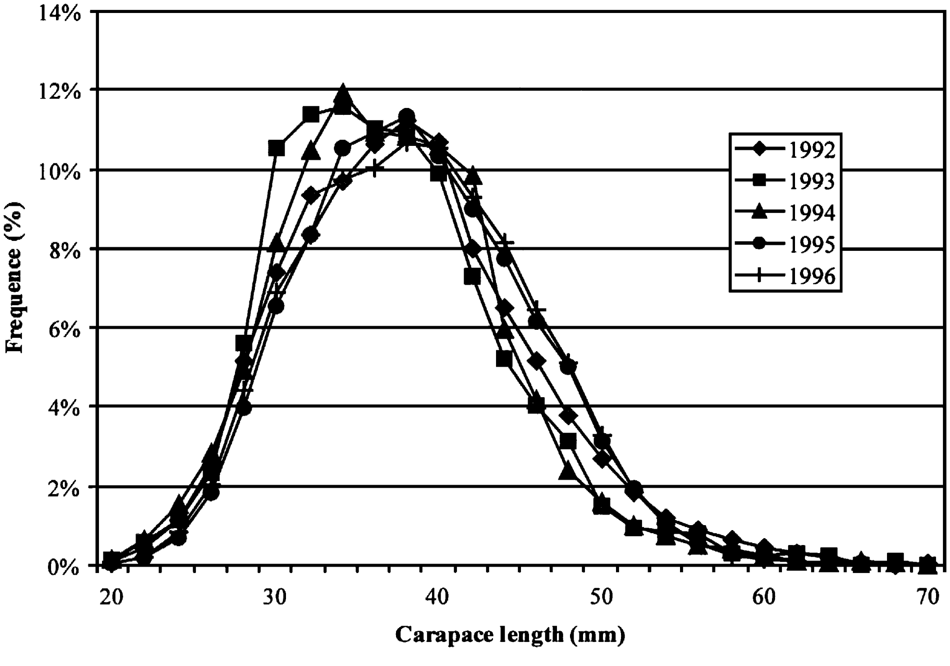

Figure 5. Yearly Size Composition of Swedish *Nephrops* Catches During 1992–96

may lead to a drastic reduction in the potential trawl harvest. The minimum landing size (MLS) of 40 mm carapace length (CL) in the Skagerrak/Kattegat area is the result of historical regulation, but is supported by recent studies of the length at the onset of female sexual maturity (figure 6). A reduction of the MLS would lead to a larger fraction of female *Nephrops* being landed without ever reproducing, a condition that has been said to violate the precautionary approach (Myers and Mertz 1998).[2]

To reduce the bycatch of undersized *Nephrops*, trawl selectivity studies have been carried out. The most promising approach is to install an eight meter section with 60mm square mesh all around the codend of the trawl. In this study, we use selectivity parameters from two 60mm square mesh codends with 60 and 100 mesh bars in circumference, respectively, for comparison with the currently legislated 70mm diamond mesh codend with 100 meshes in circumference. Selectivity parameters for the test codends are shown in table 1, and corresponding selectivity ogives are presented in figure 7. A discard mortality rate of 75% is assumed, with no significant difference in either discard mortality or escape mortality between different codends (Anon. 1998). The proportion of undersized *Nephrops* in the currently used 70mm diamond mesh trawls amounts to 55% in number and 35% in weight. Preliminary results show that for the 60 mm square mesh codend, the fraction of undersized *Nephrops* is reduced to about 20% in weight, and bycatches of other species like whiting, haddock, and cod are also drastically reduced (Ulmestrand and Valentinsson in prep.).

The Biological Model

Virtual Population Analysis (Gulland 1965) and its approximation, Cohort Analysis (Pope 1972), are standard techniques for stock assessment when historical catch-at-age data are available. In the absence of age data, which is the case for *Nephrops*, Jones (1979, 1984) suggested a Length-Cohort Analysis (LCA) in which length-frequency data are used to construct a synthetic cohort. This method has its limitations (Lai and Gallucci 1988; Hilborn and Walters 1992), but has been established for assessment of *Nephrops* stocks. The International Council for Exploration of the Sea (ICES) Working Group on *Nephrops* stocks use a modified version of LCA, when estimates of age data are missing, as an instrument for their management considerations to the Advisory Committee for Fisheries Management (Anon. 1997).

The crucial assumptions underlying LCA are: (*a*) constant recruitment, (*b*) that numbers caught can be used to calculate annual removals per length group, (*c*) that input length composition is representative of a steady-state situation, and (*d*) that growth of the species can be characterized by a von Bertalanffy curve.

A steady-state length composition is not likely to occur in practice, but according to Jones (1984, p. 27), “a useful approximation can be obtained by determining the average length composition over a period of as many years as possible. In this way the effect of fluctuations in year-class strength and mortality rates should be minimized.” This study uses length composition data from 1992–96, which was collected from commercial trawlers.[3] For the LCA, we only use the Swedish trawl log book landings and measurements on trawl catch composition from Swedish

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[2] This argument, as noted by a reviewer, is weakened by the fact that 75% of the discards die, so retention of sublegal females would have limited effect.

[3] Samples of commercial trawl catches, *i.e.*, both landings and discards, have been collected from twenty different vessels. On average, measurement has been carried out on three vessels per month, with an average number of 250 specimens from landings and discards, respectively. In total, approximately 100,000 specimens have been analyzed.

Nephrops grounds. This comprises only about 25% of total landings, which may seem to be a low figure. However, as *Nephrops* does not undertake extensive migrations (Chapman 1980); *i.e.*, emigration and immigration between subareas are near zero, migration to this part of the stock is balanced. Hence, we hold that the Swedish trawl *Nephrops* grounds can be treated as an appropriate stock definition in the LCA.

Computation in the LCA starts with the largest individuals, λ, in a length-frequency histogram and uses (Lai and Gallucci 1988)

$$N_\lambda = C_\lambda Z_\lambda / F_\lambda \tag{1}$$

and

$$N_l = N_{l+\Delta l} A_l^{M/k} + C_l A_l^{M/2k} \tag{2}$$

Table 1
Summary of Estimated *Nephrops* Selectivity Parameters for Different Trawl Codends

Mesh Size and Shape	L50 (confidence limits)	SR (confidence limits)
70 diamond	18.2 (16.3-19.8)	15.6 (13.7-17.5)
60b square	32.2 (31.3-33.2)	11.9 (9.2-14.6)
60 square	39.7 (39.2-40.3)	14.5 (13.3–14.7)

Note: L50 is 50% retention length (mm) and SR is selection range between L25 and L75.

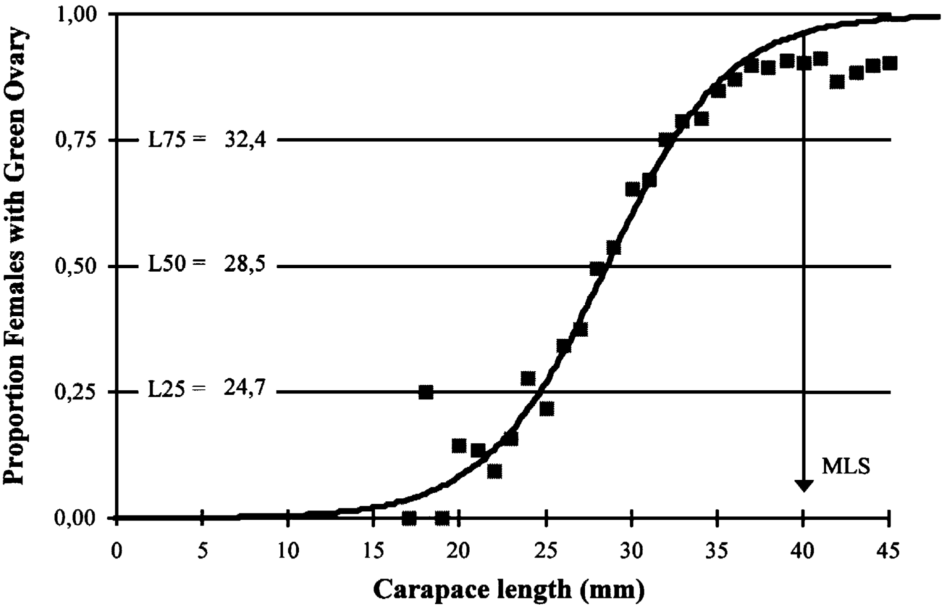

Figure 6. Onset of Sexual Maturity (Green Ovary) for Female *Nephrops* (N = 11,514), Minimum Landing Size (MLS) = 40 mm Carapace Length
Source: Ulmestrand and Eggert, unpublished

and the corresponding fishing mortality over each length interval (l, $l + \Delta l$)

$$F_l \Delta t_l = \ln(N_l / N_{l+\Delta l}) - M\Delta t_l \tag{3}$$

where N_λ is the number of individuals attaining terminal length λ; N_l is the stock size at the beginning of the length interval (l, $l + \Delta l$); C_λ is the catch in number of individuals in the terminal length interval (λ, L_∞); C_l is the catch in number assumed to occur at the middle of the length interval (l, $l + \Delta l$); $Z_l \Delta t_l$ is the total mortality of individuals in the terminal length interval (l, $l + \Delta l$); F_λ is the instantaneous fishing mortality rate of individuals in the terminal length interval (λ, L_∞); $A_l = (L_\infty - l)/[L_\infty - (l, l + \Delta l)]$; and $\Delta t_l = \ln A_l / k$, which is the time required for a fish to grow from length l to $l + \Delta l$; where L_∞ and k are von Bertalanffy growth parameters; and M is the instantaneous natural mortality rate assumed constant over all lengths.

With a constant fishing effort and a steady-state stock, the numbers caught and the average numbers in sea will remain constant over the years for each length class. The model takes into account incidental mortality caused by discard due to the minimum size regulation of *Nephrops*. Additional mortality due to, for instance, escape mortality, is not accounted for in the model.

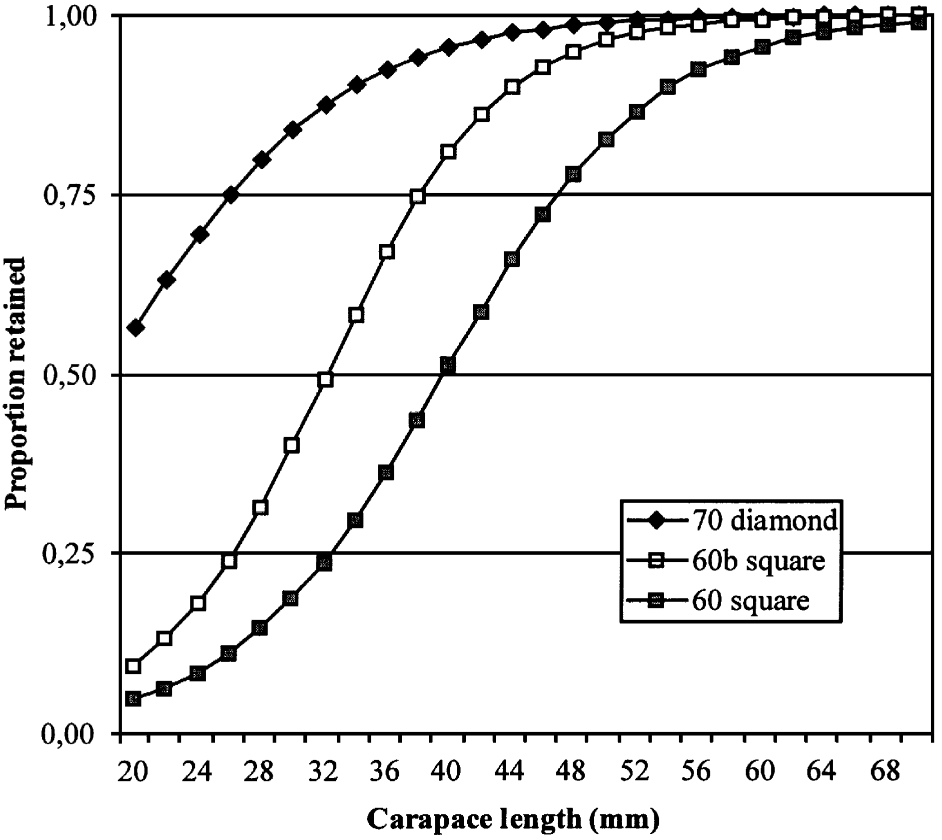

Figure 7. Trawl Selectivity Ogives for 70 mm Diamond Mesh and Two 60 mm Square Mesh Codends with Different Number of Meshes in Circumference

The growth of a single lobster is assumed to follow the von Bertalanffy growth function, where the length at age t, l_t, is estimated by

$$l_t = L_\infty\left[1 - e^{-k(t-t_0)}\right] \tag{4}$$

where t_0 is the age at which growth according to the growth equation is initiated. The length data can be converted to weight data by using the relationship

$$W_t = al_t^b \tag{5}$$

where W_t is the weight at age i, and a and b are constants. Using equation (4), the length groups can be converted to synthetic cohorts. Then an algebraic formulation of the yield, following the modified Thompson and Bell yield per recruit model by Christensen and Vestergaard (1993) is:

$$Y = \Sigma_i N_i\left[1 - e^{-(F_iS_i+M)}\right]F_iS_i/(F_iS_i + M)w_i \tag{6}$$

where N_i is the fraction of the initial recruitment that survives to age i; F_i is fishing mortality rate at age i; S_i is gear selectivity at age i; and w_i is average weight at age i.

The recruitment for year class i + 1 (survivals from i to i + 1) can be expressed as:

$$N_{i+1} = N_i * \exp\left[-F_i(S_i * D) - M\right]. \tag{7}$$

Where D takes on the value 0.75 for year classes smaller than 40 mm CL to account for discard mortality and 1.0 for year classes larger than 40 mm CL.

The fishing mortality values for year classes smaller than 40 mm do not add to the yield but lead to an extra mortality on top of the natural one. In this study, we follow the approach described by Jones (1984), where the various computational steps are combined into a single sequence. The figures for male and female Norway lobsters differ, and only a and b have been estimated for the area (Anon. 1997), while the other parameters are taken from other stocks in the literature. L_∞ is 78 and 67 mm, respectively, k_{male} is 0.16 and k_{female} is 0.1, while t_0 is –0.05, a is 0.00045 and 0.00108, and b is 3.11 and 2.85, respectively. The terminal F is assumed to be 0.3 for both sexes. The figures of natural mortality, M_{male} and M_{female}, for the area are still not accurately determined, which leaves us with the estimates from the Scottish *Nephrops* fishery (Anon. 1997), $M_{male} = 0.3$ and $M_{female} = 0.2$. The necessary input data are values for L_∞, the values for M/k, and a value for F_λ/Z_λ. Detailed tables with input and output LCA results are available from the authors.

Standardization of Fishing Effort

The link between the biological model in the previous section and the economic model is provided by the fishing mortality, F. A proportional relationship between fishing mortality and effort is assumed. The Swedish *Nephrops* trawling fleet encompasses approximately 200 vessels with various characteristics. Gross register tons (GRT) span from 1 to 300, crew number from one to three, and engine power from 20 to 1,000 kW. In empirical studies, an aggregate measure of fishing effort for the whole fleet is often used, while sometimes a group of similar reference trawlers can be identified to calculate the total effort as the ratio between total landings and LPUE for the reference fleet. In this study, we use the latter approach described by Gulland (1983).

A thorough examination of the 67 vessels that landed more than 5 mt *Nephrops* in 1995 showed that LPUE is independent of boat size. The fluctuation in LPUE around the average of 8.5 kg/trawl hour is approximately the same for different vessel sizes (figure 8). An LPUE independent of vessel size is puzzling from an economic point of view. Possible explanations are that bycatches are not included and may be increasing by vessel size, and that effort figures are solely trawling hours and do not include steaming time. According to the fishers, small vessels steam to reach “hot spots,” while medium vessels set the trawl when *Nephrops* grounds are reached, and large vessels set the trawl and then pass both *Nephrops* grounds and outside *Nephrops* grounds. The result is that total landing value per fishing day is likely to increase by size, which, unfortunately, could not be confirmed given the data available, but remains an important aspect for any kind of regulation. However, for our analysis we use the fact that, *ceteris paribus,* one standard trawl hour implies the same catch. Since 1989, an increasing part of the fleet has shifted from single to twin trawls, and in 1995, roughly half of the trawl landings came from twin-trawl vessels. The average specialized *Nephrops* trawler spent 1,280 standardized trawl hours, landing 10.9 mt in 1995.[4]

The Economic Model

A fish stock can be considered a capital stock. Abstaining from fishing can be seen as an investment in the stock and vice versa. Since the paper by Clark and Munro (1975), much attention has been given to discussions on the optimal path to the optimal stock level. As noted above, LCA is based on the assumption of a steady-state equilibrium. For the case of *Nephrops*, a change in effort or selection pattern will lead to a new equilibrium after five or six years. For the purpose of this analysis, we assume that a sole owner, whose objective is to maximize net revenue, manages the resource. The focus is on determining the long-run, optimal steady-state stock and hence, all costs. Short-run fixed costs are assumed variable. We also assume that price is independent of variations in Swedish landings, which seems plausible, as the Danish and Swedish markets are similar to a large extent.

Out of the 67 reference trawlers specializing in *Nephrops* fishing, detailed information on costs and revenues were obtained from a sample of 20 trawlers. Both the 67 and the 20 sample trawlers showed an average LPUE of 8.5kg/standard trawl hour, where *Nephrops* landings accounted for more than 40% of total earnings. Based on the similarities in LPUE and vessel characteristics, we consider the sample to be fairly representative.[5] These figures were used to apportion the costs of a trawler specializing in the *Nephrops* fishery. On average, 60% of the income comes from *Nephrops*, while the rest is from demersal species, where cod is the single most important species. We use the simplifying assumption of perfect foresight; *i.e.*, fishers allocate their effort in the same proportion as the actual landings (in monetary

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[4] Median and average values for the 67 vessels are roughly the same; *i.e.*, LOA 16.5 m, 40 GRT, and 245 kW.

[5] The average (SD) in LOA (m), GRT and engine power (kW) for the 67 and the 20 sampled trawlers were 16 (3.2), 43 (24), 240 (67), and 15 (3.3), 40 (26), 220 (61), respectively.

terms). The consequence is that 60% of the total costs are assumed to be incurred in support of annual landings of *Nephrops*.

Table 2 summarizes the cost figures for a representative *Nephrops* trawler, which, on average, earned US$124,000. The user cost of capital is calculated by using the average insurance value of the vessels, assuming linear depreciation over 20 years, and calculating the imputed opportunity cost for a real interest rate of 5%.[6] Operation costs are average values, including maintenance, fuel, water, ice, administration, *etc*. We use the zero profit assumption for open-access equilibrium. Total revenues minus operation and capital costs correspond to the labor cost. It is notable

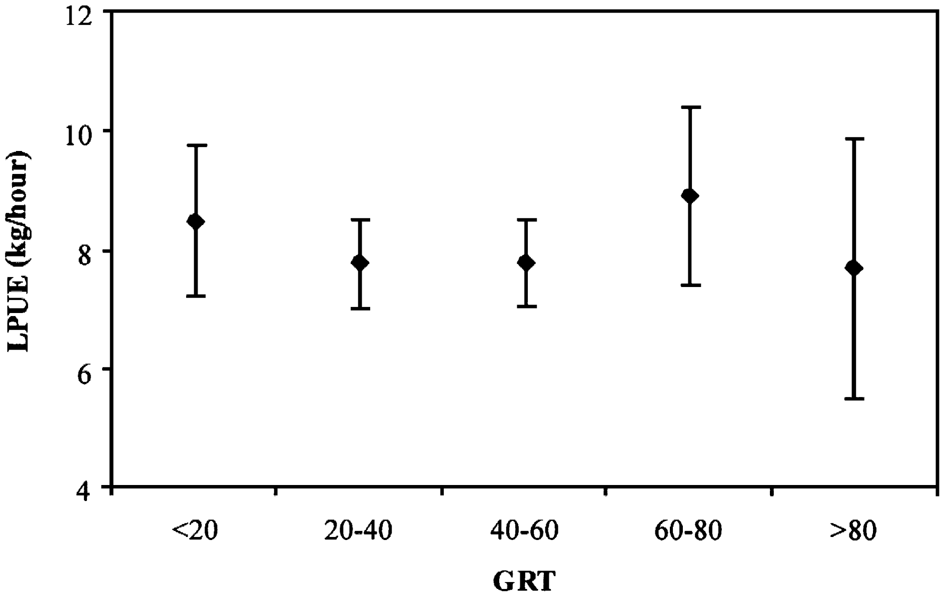

Figure 8. Average LPUE with Respect to Vessel Size (GRT). *N* = 67 (log book data). Note: Error bars show standard error

Table 2
Costs of the Reference Trawler 1995 (‘000 US$)

	Low	High
Capital Cost	15'	15'
Operation Cost		
Fixed	34'	34'
Variable	25'	25'
Labor Cost	25'	50'
Total	99'	124'
60%	59.4'	74.4'

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[6] The average real rate of return on Swedish government bonds during 1990–96 was 5%.

that with this approach, the return on labor does not increase with vessel size. In fact, one of the highest labor income per crew member was earned by a small trawler. As in most fisheries, wages in the *Nephrops* fishery are based on a share system, remuneration of US$50,000 per vessel with two people on board corresponds to a monthly salary of about US$1,600. This wage is quite low compared to the average of US$1,800 paid to a Swedish nonskilled worker in 1995 (Statistics Sweden 1997). Two major factors that may explain these conditions are the accounting of capital and operation costs and unreported landings. The cost figures for some of the vessels covered 1992–96 and showed that the real insurance value was constant. This observation was also supported by personal communication with several fishers, and despite the limited second-hand market for trawlers, a few actual transactions took place and were settled at prices close to the insurance value. In 1995, the scrap premium from the European Union was US$1,500/GRT, which implied a scrap value close to the insurance value for most vessels. The oldest vessel in the fleet was almost 70 years old, while the average age was 30 years. The overall impression is that individuals do not perceive a depreciation cost, and that the capital cost may be overestimated from a social point of view. Possible reasons are that part of the maintenance costs are, in fact, reinvestments, and the cost of increased risk for breakdown with age is borne via a higher insurance premium. The scrap premium has probably influenced the second-hand price of vessels. However, in 1996, the scrap premium was reduced by 35%, but neither a change in insurance values, nor transaction prices was observed. There is, of course, a social depreciation cost, but it may partly be double counted, as reinvestment and higher insurance premiums are not properly identified. We have no reason to believe that the actual cost figures are exaggerated, but possibly underestimated, as some maintenance work may be carried out by the fishers themselves or as nontaxed work. A major part of trawl landings, 60–70%, comes from vessels located in the northern part of the Swedish West Coast, which is entitled to rural support according to the European Union. Given that alternative employment opportunities are scarce, the social opportunity cost of labor is significantly lower than the actual earnings. The low-cost alternative represents such a situation, where only half of the actual labor cost is accounted for.

On the revenue side, our figures are less certain. The occurrence of unreported landings has been much debated in Sweden recently (Hultkrantz, Stigberg, and Hasselberg 1997). Exact assessments are absent, but there is a consensus that unreported landings occur. For a valuable species like *Nephrops*, the profits from unreported sales are high. By abstaining from paying sales provision, social insurance, and income tax, the fisher gets a net revenue from an unreported landing that is at least double the net revenue from a reported landing. Unreported sales (7–8%) of *Nephrops* would correspond to a monthly salary before tax of about US$2,000, which is significantly higher than the average Swedish nonskilled worker. It should be noted that potential unreported landings do not affect the stock assessment, which is based on repeated length analysis of complete catches, including undersized individuals. There is no enforcing element in the length analysis reports, as the link to total catches is hard to establish, and, with no incentive for misreporting, the underlying figures for the biological parameter estimates are judged to be precise.

Open-access equilibrium is determined as the zero expected profit case for the high-cost alternative, while maximum economic yield is achieved from maximizing the profit for the static case. Sandal and Steinshamn (1997) have recently shown that in the case of inelastic demand and/or increasing marginal cost, a higher discount rate can imply a larger standing stock. The same applies for Hannesson's (1986) model, which takes capital dynamics into account. But for a valuable species, assuming linear effort costs and a constant price, the conclusion of Clark (1990) that a positive discount rate implies a smaller standing stock is most likely to be valid. In this study, no discounted equilibrium is determined, but for policy guidance it can be concluded that the MEY figures represent minimum figures for optimal effort levels. As a comparison, Clarke, Yoshimoto, and Pooley (1992) calculated the optimum effort for various discount rates for five different simple stock growth models. The 5% discount rate level compared to the zero case implied increases in the optimum effort level, which ranged from 1 to 8%.

Results

The Trawl Fishery for Nephrops

The estimated revenue curves and two different cost curves are shown in figure 9. The yield curves 60 square and 60b square represent the higher and the lower limits from the results of square mesh tests, respectively (Ulmestrand and Valentinsson in prep.). We find that the Swedish *Nephrops* trawler fleet applied an effort of 94,000 standard trawl hours, leading to landings of 803 mt at a value of US$5.6 million, which corresponds to an open-access equilibrium where profits are zero. If we do not assume perfect labor mobility in and out of the fishery, and instead assume the existence of persistent unemployment, the low-cost alternative might be a more accurate description of the current situation. In such a case, this fishery does, indeed, entail a positive net welfare contribution to society, but this social resource rent

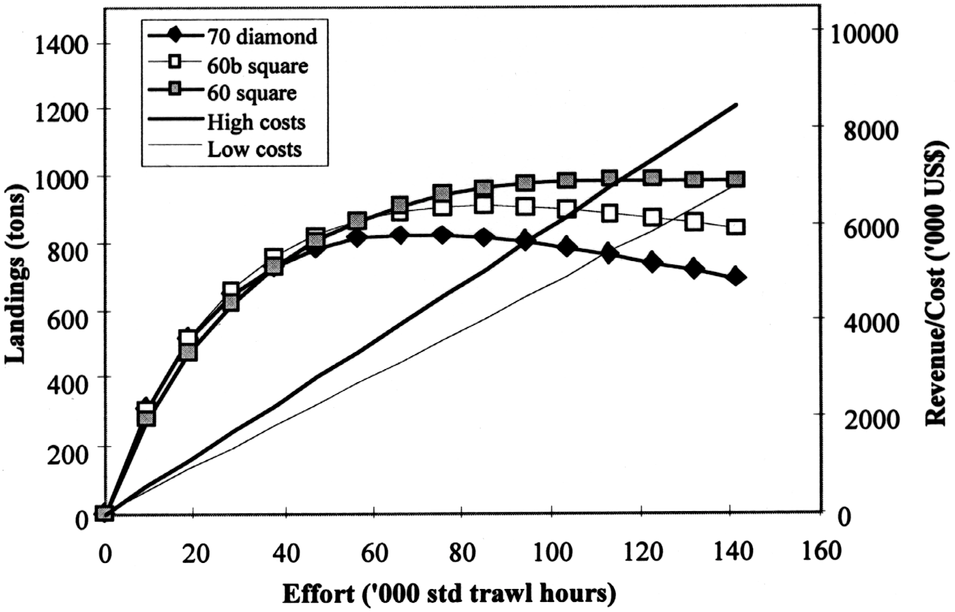

Figure 9. Estimated Yield for 70 mm Diamond Mesh and Two 60 mm Square Mesh Codends With Different Number of Meshes in Circumference and Cost Curves

Note: Natural mortality is assumed to be 0.2 for females and 0.3 for males could be increased if effort is reduced and/or if square mesh is introduced. Using the high cost figures, MEY is found at a level of 35,000 standard trawl hours, where the resource rent is estimated to US$2.9 million. If a square mesh regulation is introduced, we expect the MEY to be around 38,500–43,500 standard trawl hours and the resource rent to be slightly increased to US$3 million. However, with a solely mesh regulation, effort and landings are expected to increase, producing a value of US$6–7 million, but with the rent still completely dissipated.

It should be noted that the higher revenue per unit effort when using the square mesh is only valid when considering the long-term, due to the reduction in discards and accompanying discard mortality. The short-term result of using a square mesh codend is that a few more full-sized individuals are lost compared to diamond mesh (see figure 7).

Table 3 provides a sensitivity test of the robustness of the results with respect to natural mortality. In case of a higher natural mortality, MEY effort levels are slightly higher, while the potential rent is drastically reduced. Even for the highest natural mortality level combined with the low-cost figures, MEY requires a drastic reduction of the effort level, and there is a significant potential resource rent to be earned. It should be stressed that the natural mortality and the von Bertalanffy parameters are assumed constant, regardless of stock size. In reality, increased natural mortality and reduced individual growth are likely effects of a major increase in stock size, which imply a higher MEY effort level and a lower rent.

Lai and Gallucci (1988) derive the analytical expressions for the errors in stock abundance and fishing mortality that would result from different deviations of estimates from true parameter values. The most sensitive parameter is natural mortality, where a difference of ±0.1 in M leads to a 40-50% error in the estimates of stock size. It is obvious that LCA results must be taken with great caution and that the MEY figures of effort levels and rent are most uncertain. Still, with all reservations in mind, a large body of empirical studies implies that the value of M is within the range given in table 3, and the case for a reduction in effort is unambiguous.

The In-shore Creel Fishery for Nephrops

Total creel landings in 1995 amounted to 111 mt, and thanks to a higher quality and larger mean size, earned about US$8.5 per kg, giving a total landing value of almost US$1 million. Table 4 shows the economic figures of an average, full-time creel fisher, which are based on twelve observations from six vessels.[7] Annual landings amount to US$30,000, while costs are divided into capital costs, fixed and variable operation costs, and labor costs, using the same assumptions as for trawlers, except for a lower labor cost.

As can be seen in table 4, the high-cost alternative leads to a deficit. If we assume a lack of alternative job opportunities and use the low-cost alternative, income equals costs. A lower labor cost, compared to trawl fishers, can be motivated by the fact that creel fishers generally work notably less hours and are exposed to a lower risk thanks to lower fixed costs. However, the labor cost figure corresponds to monthly earnings of less than US$1,300. The reported average earnings minus reported average costs, excluding labor cost, imply a monthly salary less than US$700. These extremely low wage figures indirectly suggest the occurrence of unreported landings, and several additional factors support such an assumption. First,

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[7] The average (SD) in LOA (m), GRT, and engine power (kW) for the creel fisher fleet and the 6 sampled vessels were 8.2 (1.3), 2.9 (2.4), 65 (49), and 8.3 (1.0), 4.0 (4.5) and 69 (29), respectively.

Table 3
Maximum Economic Yield Effort Levels, Long-term Increase in Landings, and Long-term Resource Rent for Different Values of the Natural Mortality Rate (M) and Two Levels of Costs

		Maximum Economic Yield Effort (standard trawl hours)			Long-term Annual Resource Rent ($US thousands)		
M (fem/male)	Costs	70	60b	60	70	60b	60
0.1/0.2	High	28,500	31,000	35,000	5,050	5,370	5,520
	Low	24,000	25,500	28,000	5,180	5,420	5,480
0.2/0.3	High	35,000	38,500	43,500	2,920	3,060	2,920
	Low	39,500	43,000	50,500	3,370	3,550	3,490
0.3/0.4	High	38,000	41,500	43,000	1,700	1,720	1,370
	Low	45,500	51,000	57,000	2,200	2,270	1,960

Table 4
Costs of the Reference Creel Fisher 1995 (‘000 US$)

	Low	High
Capital Cost	5'	5'
Operation Cost		
Fixed	11'	11'
Variable	4'	4'
Labor Cost	10'	20'
Total	30'	40'

creel fishers have shorter working hours and possibly lower opportunity cost of time. Second, earlier studies carried out at the Institute of Marine Research, Lysekil (Ulmestrand, unpublished data), indicate that the daily catch per creel figures imply higher total landings. Finally, there are annually repeated reductions in reported landings during July, when summer visitors and tourists crowd the most frequently used landing port. With these factors in mind, we have good reasons to believe that unreported landings are more extensive among creel fishers than among trawl fishers. For example, if there were 20% unreported landings, earnings would correspond to a monthly salary of almost US$1,600, which is more in line with wages from alternative job opportunities.

Comparison of the Trawl and Creel Fisheries

The creel fishery has several potential advantages over the trawl fishery. Firstly, it has most likely a smaller environmental impact. Fuel consumption is lower, and the impact on the benthic fauna and flora is small. The latter is a factor which has increased in importance as securing biodiversity is an obligation of the Government of Sweden vis-à-vis the European Union and the Rio Agreement. Secondly, mortality rates for undersized discards from the creel fishery are almost zero (Anon. 1998). Finally, the gentle catch method yields more lively lobsters, which receive a higher price.

The negative external effects on the environment from fossil fuels have raised to the top of the political agenda during the last decade. A creel fisher consumes five to ten cubic meters of diesel annually, while the corresponding figure for a trawler is 40–50 cubic meters. Assessments of the external cost caused by emissions from diesel engines in fishing vessels are absent in the literature. We use US$74 per cubic meter consumed as a crude proxy, which accounts only for particle emissions from diesel trucks in rural areas (Johansson 1995). Recalling that the landing value of a trawler is more than four times that of a creel fisher, the external cost from fuel emissions is 2–3% of the total landing value for a trawler, while the corresponding figure for a creel fisher is 1–2%, and hence, the difference is minor.

To assess potential damages from bottom trawling is far from trivial. The current extent and intensity of fishing, using mobile fishing gears like trawls and dredges, is widely considered to cause physical disturbance of the sea floor and forms a serious and growing threat to diversity and production in marine benthic habitats (De Groot 1984; Lindeboom 1995). This has raised concerns as to the extent to which trawling may cause long-term and large-scale changes in the diversity and composition of benthic marine assemblages (Jones 1992; Lindeboom 1995; Kaiser and Spencer 1996). Several studies using optic or sonar techniques have demonstrated that scraping and ploughing by mobile fishing gear may have profound effects on the physical structure of benthic soft-sediment habitats (Kaiser 1996; Schwinghamer, Guigne, and Siu 1996; Service and Magorrian 1997; Tuck *et al.* 1998). Furthermore, direct contact with trawls and dredges may cause damage to individual benthic organisms (De Groot 1984; Gilkinson *et al.* 1998). For practical reasons, most studies on trawl effects comprise only one control area and one treatment area. The lack of independent replicates of the treatment and control areas makes interpretation of results difficult, and it is unclear whether any discovered changes in benthic fauna are actually caused by the experimental treatment or by other reasons. Therefore, it is very important to investigate the extent of variability in temporal change among potential control areas and what practical consequences such variability may have for the interpretation of experiments on effects of mobile fishing gear on benthic soft-sediment fauna. It is, at present, not possible to assess the implications of *Nephrops* trawling on the benthic fauna and associated costs. Results from a fully replicated study of in-shore trawling by a small vessel indicate a minor impact on large macro fauna (Hansson *et al.* 1997). Still, those results may not be applicable for *Nephrops* trawling.

The effects of discard mortality for undersized lobster close to zero and a 20% higher price for creel caught *Nephrops*, are captured by the costs and earnings data. The underlying assumptions of constant recruitment and no migration between trawl and creel fishing grounds imply that there is no interaction between the two fisheries. This means that the high discard mortality rates only affect the trawl fishery, while the benefits of the creel fishery only accrue to the creel fishers. Still, the reported economic performance of the creel fishery is significantly worse than that of the trawl fishery.

There is one factor in favor of the trawl fishery, the sex composition of catches. During the period December to February, females are berried (carrying external eggs) and the natural behavior for them is to stay below the bottom surface, which results in a composition of 80% males in the trawl catches for the given period. Creels are baited, and the females cannot resist such temptation, leading to a fifty-fifty composition for creel landings, even during the fertile period. An intensive creel fishery may, in this manner, have a negative impact on the stock via recruitment overfishing. Given current knowledge, it is impossible to judge whether the creel fishery during previous years has had an impact on recruitment for the stock within the archipelago.

Discussion and Conclusion

In this study, we have applied a bioeconomic model to empirical data from the Swedish trawl fishery to estimate the optimal effort level by linking a length cohort model to a net revenue function. There are several limitations, like uncertainties in biological and economic parameters. Concerning the biological model, we think the strict assumptions for an LCA and the assumed growth parameters, which are taken from other stocks in the literature, are the weakest parts. In an ideal situation, effort and landings are constant for many years to meet the steady state requirement for an LCA. If not, recruitment and exploitation rates should have been stable, on average, with no significant trends in either (Hilborn and Walters 1992), which are conditions fairly well met by the years 1992–96 used here (recruitment is constant by assumption, but unknown). The economic model also has limitations. Figures collected from tax reports are likely to be biased on the revenue side, and the assumption of constant marginal costs can be questioned. Yet, using increasing marginal costs will not significantly change the results (Anderson 1982). Next, we have tried to compare the trawl and the creel fisheries in terms of qualitative aspects as well as economic performance. The existing creel fishery data does not allow for an LCA, which means that the potential net revenue from a MEY creel fishery is unknown. Further, the effects on benthos from bottom trawling are unknown and cannot be assigned an economic value. Overall, one should note that the results from this study must be interpreted with some caution.

The Swedish *Nephrops* fishery is the country's most valuable coastal fishery. It encompasses a great variety of vessels, from 300 GRT trawlers down to single owner-operated 1 GRT boats. The high minimum landing size, together with the currently legislated 70mm diamond mesh, leads to high discard rates. Introducing a square mesh codend can significantly reduce the discard rates. Despite the theoretical loss in landings, some fishers have voluntarily shifted to square meshes and claim that the overall performance is superior to the diamond meshes. This would be due to simplified handling of the catch, and leads to cleaner and more lively catches, and even a higher catch rate. The latter would be thanks to a reduced weight of bycatch, which, in turn, leads to a better bottom contact of the trawl. The short-term effects of a shift to square mesh codend may be disputed, but in the long-run, landings will unambiguously be equal or higher for all effort levels.

For the trawl fishery, we estimate a potential annual resource rent of almost US$3 million for the MEY equilibrium. To achieve MEY, it is necessary to reduce the long-term effort level by 60% from the present level.[8] Given the uncertainty of biological and economic parameters and the likely political resistance to carry out such drastic reduction of effort, a successful regulation is likely to be designed to approach this level gradually.

In the case of gear regulation, one should bear in mind that the current fishery is roughly characterized as an open-access regime. A single management measure of a

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[8] As noted earlier, unreported landings will not affect the LCA, but change the scales of the x- and y-axes in figure 9. If landings are 10% higher than reported and effort figures are correct, then the correct MEY is 10% higher, and the MEY effort level is unchanged.

mesh regulation would, therefore, only lead to an increased effort level, where the higher, long-term landings will be offset by increased costs, and the resource rent will remain completely dissipated. The mesh regulation is, in itself, amiable, but should be accompanied by a set of measures. At present, new vessels are heavily subsidized by 25% grants from the European Union, and, at the same time, scrap premiums are offered. Such policies are not in accordance with economic theory. They are also likely to increase the average size of the vessels, while the economic figures collected for this study show that smaller vessels might well outperform the larger ones. Most of the *Nephrops* trawlers are partly dependent on landings of other demersal species, with cod being the most valuable. Because the TAC for cod has repeatedly been binding during the 1990s, an increase of catch capacity is undesirable. Individual Transferable Quotas (ITQs) are an often advocated policy instrument in the literature. Another suggestion is Territorial Use Rights in Fisheries (TURFs), which could be allocated among local fishing communities (see Hannesson 1993). It is beyond the scope of this study to judge which policy instrument is the most adequate for the Scandinavian *Nephrops* trawl fishery. Yet, given that the suggested mesh regulation is imposed in both Denmark and Sweden, it is an important task for future research to investigate which policy instrument is the most suitable for this fishery.

For the creel fishery, we identify several attractive features. However, despite the zero discard mortality and the higher price per kg, the reported economic performance of the creel fishery is poor compared to the trawl fishery. Concerning the impact on the environment, the difference in emission levels per landed value is minor. The possible adverse effects of repeated bottom trawling remain a concern. It is possible that future research will show that protection of some rare benthic communities can be justified for bioeconomic reasons. Such measures may reduce the net revenue from trawling, but it will not improve the net revenue from creel fishing. The open-access characteristics of the creel fishery seem to imply nonprofitable conditions for the fishers. This situation could possibly be improved if the number of creel fishers is reduced, but the overall impression is that the fishery is partly dependent on the possibility of unreported landings. In a more general context, reduced tax burden on low-skilled workers is proposed as a means of reducing long-term unemployment (Bovenberg 1995). Such policy could apply to the creel fishery, again given that the number of fishers is restricted. From the reported figures, the impression that the fishers are partly dependent on unreported landings is unambiguous. As it stands, the current performance of the creel fishery does not provide a rationale for expansion of the trawl protected area at the expense of trawl fishing. If the effects of bottom trawling are found to be unacceptable, a likely solution would be the introduction of marine protected areas.

The major policy instrument for all European *Nephrops* fisheries is TACs, which were not binding in any of the eighteen management areas in 1995. In some areas, landings equaled the TAC, but in reality, renegotiation follows immediately when the TAC is reached. Except for Iceland, there are no economic policy instruments in use, and the rough landing value of US$200 million in 1995 implies a significant potential resource rent to be earned from *Nephrops* landings. This is essential information for the Multi-Annual Guidance Programme, an element within the European Union's Common Fisheries Policy, which seeks to reduce fleets to a size consistent with the available fishing opportunities. To our knowledge, this is the first bioeconomic study of *Nephrops* fisheries, and future research could shed further light on: (*i*) the potential of decommissioning programs, (*ii*) the scope for creel fishing compared to trawl fishing, and (*iii*) adequate design of policy instruments to reestablish the dissipated resource rent.

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