Fishing practice, gear design, and the ecosystem approach—three case studies demonstrating the effect of management strategy on gear selectivity and discards

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A basic tenet of the ecosystem approach to fisheries management is that harvesting is conducted with minimal impact on juvenile fish, non-target species, and marine habitats. A range of technical modifications of fishing gears aimed at improving their selective properties is available to help achieve these goals, but their effectiveness varies. Through three case studies, we describe how management controls influence fishing behaviour and the adoption of more selective gear, and demonstrate how conservation goals can be discouraged or encouraged by the strategy. In Norway, limits set on the maximum quantity of sublegal fish that may be retained on board, in combination with a ban on discarding, resulted in substantial area closures in the Barents Sea. Therefore, to gain access, fishers developed technical modifications to enhance gear selectivity. In both shrimp and demersal trawl fisheries, the modifications are now being used by virtually the whole fleet. To reduce cod mortality in the North Sea, mesh sizes were increased and effort restrictions introduced, but the measures also affected other fleets, notably those targeting *Nephrops*: fishers for that species reduced their mesh size to prevent loss of target species and to avoid effort restrictions. Although management measures may have resulted in reduced fishing mortality on cod, they placed additional pressure on other stocks by encouraging vessels to switch gears, and it is likely that discard rates have increased. In the eastern Bering Sea fishery for walleye pollock, the adoption of more-selective fishing gears was encouraged by regulations requiring fisheries to be curtailed when bycatch rates of prohibited species are exceeded, leading to underutilization of the target species through premature closures. Fishers now act cooperatively by providing real-time data on bycatch hot spots, allowing tactical fishing decisions to be taken to avoid such areas.

Keywords: bycatch, discards, fisheries management, gear selectivity.

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Introduction

Fishers discard part of their catch for a variety of reasons, generally either for market/economic considerations or to comply with regulations. Lack of marketing opportunities, quality considerations, or large price differentials between or within species (high-grading) all induce discarding (Alverson *et al.*, 1994; Kelleher, 2005). Crean and Symes (1994) note that the management framework has a strong influence on discard rates. Fisheries that are managed extensively by output controls [such as total allowable catch (TAC) and catch composition regulations] are often characterized by high discard rates.

Discarding in multispecies fisheries may be induced by quota regulations. When the quota for one species is exhausted but opportunities remain for others, fishers sometimes continue fishing for other species and discard the first species. Similarly, regulations setting limits on percentage catch composition on board may compel fishers to discard excess catches of certain species.

Fishers are aware that regulatory discarding of marketable dead fish serves no conservation purpose. This undermines their faith in the management system and can lead to non-compliance and illegal landings. Quota-induced discarding may be reduced by restricting effort or by setting lower quota for all species caught in the mixed fishery, to protect the most vulnerable ones. However, this may result in underutilization of the target resource.

Retention of undersized fish results from a mismatch between the selectivity characteristics of the gear (specifically the legal minimum mesh size, MMS; an input control issue) and the legal minimum landing size (MLS; an output control issue). Fisheries targeting species suffering from overexploitation tend to be characterized by relatively high discard rates. Not only is the natural balance shifted towards an excess of relatively small individuals in the population, but fishers may also increasingly target smaller fish to maximize catches of fish above MLS. Increasing the mesh size under such circumstances can result in an unacceptably large loss of landings, and an incentive to reduce gear selectivity to retain as many fish above MLS as possible (Cook, 2003).

This problem is even more acute in multispecies fisheries, in which each target species has its specific MLS that may not be tuned to the size selectivity of the prescribed mesh size. The MMS permitted in the southern North Sea beam trawl fishery for sole and plaice is 80 mm. The MLS of sole (24 cm) corresponds roughly to the 50% retention length at such a mesh size, but the gear retains plaice considerably smaller than the MLS of 27 cm, resulting in high discard rates. However, a simple increase in mesh size to reduce discarding of plaice would result in considerable short-term losses of marketable sole (ICES, 2005). Sole at the MLS tend to have the greatest market value of all size grades.

It is this interplay of fishing gear, species assemblage, market demands, and the regulatory framework that influences the quantity and composition of discards produced. We discuss the influence of the regulatory framework on the type of fishing gear employed by fishers and on their strategic decisions, through three case studies.

Case 1: discard and bycatch management in Norwegian fisheries

Regulatory framework

Before 1983, technical regulations in Norwegian territorial waters were based largely on the North East Atlantic Fisheries Commission (NEAFC) management regime, a combination of MMS, MLS, and TAC regulations. Retention on board and landing of fish less than the MLS was prohibited, resulting in some discarding. During the early 1980s, the Barents Sea cod (*Gadus morhua*) stock was in poor condition, caused by an extended period of low recruitment, and a surveillance programme suggested that seasonal, spatial closures should help to protect juveniles. Such closures were introduced in 1983 along with regulations that made it obligatory to change fishing grounds if catches exceeded specified levels of certain species less than the MLS (Løbach and Veim, 1996; Huse *et al.*, 2003). In the trawl and seine fisheries for cod and haddock (*Melanogrammus aeglefinus*), the trigger was set at 15% by number, whereas in the *Pandalus* (shrimp) trawl fishery, an area closure is triggered by a varying number of cod, haddock, and redfish per tonne of *Pandalus* catch.

The year 1983 produced a strong year class of cod, and when it reached MLS, fishers started taking big catches, suggesting that the area closures and catch limits had provided significant protection to the spawning stock. A sequence of events then unfolded as a direct result of the bycatch restrictions. First, fishers began to high-grade because of the volumes of fish taken. This reduced their confidence in stock assessments, because discarding was not monitored accurately. Discarding was considered by many to constitute a waste of valuable resource and therefore to be a political issue. In 1988, a ban on discarding fish at sea was introduced, a ban that now applies to 16 species of fish and shellfish. The ban was an attempt to obtain better information on total catches (rather than landings) and to outlaw such wastage. Any fish (over quota or sublegal length) caught had to be landed and deducted from the TAC. The conservation philosophy underpinning these regulations represented a shift towards a policy directed at the fishing operation, aimed at imposing a minimum catching size, as opposed to a MLS. This sent a clear signal to those engaged in the fishery that unwanted fish should not be retained by the fishing operation before the catch was brought on board.

Opening and closing areas is effected through observers monitoring catch composition on representative commercial vessels. The process is relatively quick. Once a survey records excessively high concentrations of fish of sublegal size, the Directorate of Fisheries notifies the coastguard and the fishing industry of the closure, which can then be implemented in a matter of hours. Monitoring continues until catch rates fall below the trigger level. Vessels can also be requested to move to alternative fishing areas if their catch exceeds the composition limits determined during a coastguard inspection. Relocation must be to an area at least five nautical miles away, and if the catch composition still exceeds the bycatch limit, the vessel needs to move again.

Impact on fleet behaviour

The discard ban is broadly supported by the fishing industry, but is unlikely to protect sublegal fish to a large extent, because it does not result in a real reduction in mortality. The ban does, however, reduce unaccounted mortality, and therefore a bias in scientific assessments, although the lack of systematic collection of discard data precludes the possibility of evaluating its effect on discard rates. By requiring the landing of all fish of illegal size, the ban overcomes a contentious aspect of current EU policy that requires discarding of over-quota fish. Under the Norwegian system, all catches are counted against the quota, and the sale value is given to the marketing organization.

The introduction of area closures has had a large impact on certain fleets. Large areas in the Barents Sea have been closed because of high rates of retention of small fish and, during certain times and years, this can account for almost half the Barents Sea area. The coastal and offshore shrimp fleets have been severely affected by the small mesh size needed to retain their target species. As a consequence, fishers had a strong incentive to find technical solutions to improve species selectivity of their gear and hence to maintain access to fishing areas by complying with catch composition regulations.

Fishers from the Nordmøre region began experimenting with rigid grids inserted in their trawls. These devices allowed the passage of shrimp through the horizontal bars, while physically inhibiting the passage of larger fish that were guided up the bars and out of an escape hole inserted above the grid (Isaksen *et al.*, 1992). This development was also partly influenced by pressure from coastal gillnet and seine-net fishers, who considered shrimp fishing a "dirty" method that did damage to "their" stocks. Following the initial successes with the device, a dispensation was agreed with the Directorate of Fisheries whereby vessels were allowed to operate in closed areas under supervision. Bycatches were greatly reduced and, within a short time, most shrimp vessels were using the Nordmøre grid voluntarily. In 1993, Norwegian and Russian authorities agreed to mandate the use of the grid throughout the Barents Sea. However, when a low biomass of shrimp coincides with strong year classes of bycatch species, the rates of bycatch can still trigger temporary closures. Research, strongly supported by the fishing industry, is ongoing to improve the sorting efficiency of the Nordmøre grid. The use of this technology has spread beyond the Barents Sea and is now mandatory in all *Pandalus* fisheries in the North

Atlantic, including Canada, the USA, the Faroe Islands, Iceland, and Greenland.

Although the Nordmøre grid provided the shrimp fleet with access to considerably larger areas than before, the demersal trawl fleet still had to contend with large area closures. Following this success story, investigations started to use grid technology to improve the size selectivity of cod trawls. Simply increasing the mesh size to release sublegal fish in sufficient quantities was believed to result in the loss of substantial quantities of marketable fish, because of the large selection range of conventional diamond-mesh codends. Trials conducted in the early 1990s demonstrated that the use of fish grids improved compliance with catch composition regulations sufficiently for the authorities to allow fishers access to closed areas (Isaksen *et al.*, 1992). Consequently, more than 100 Norwegian vessels were using this grid on a voluntary basis by the mid-1990s (Løbach and Veim, 1996). The Norwegian and Russian authorities mandated its use in the entire Barents Sea in 1997.

The effectiveness of the grid and the mesh in reducing the capture of sublegal fish can be judged by comparing the minimum catch size (MCS = 47 cm) with the selectivity of the 135 mm codend and 55 mm grid. The MCS coincides approximately with the length at which a fish has a 15% probability of being retained (Jørgensen *et al.*, 2005).

Case 2: mixed whitefish/*Nephrops* fishery in the North Sea

Types of regulation

The EU *Nephrops* fishery in the North Sea is managed by three regulatory mechanisms. Output is restricted by TACs allocated annually to countries according to their historical shares. Exploitation patterns may be modified by technical conservation measures specifying gear restrictions (e.g. MMS) and MLS, and input has been controlled since 2003 by limiting days at sea by month or year.

Several distinct categories within the *Nephrops* fishery have been identified by cluster analysis of Scottish landings from the North Sea. Based on the proportion landed by weight, they vary from offshore fisheries with 35–40% *Nephrops* to clean inshore fisheries with nearly 100% *Nephrops*. The mixed fisheries have an economically important bycatch of roundfish, anglerfish (*Lophius* spp.), or flatfish, but are required to have at least 30% *Nephrops* in their catch to use mesh sizes <100 mm.

The Fladen area off northeast Scotland (which delivered some half the total North Sea landings of *Nephrops* in 2004) supports such mixed fisheries. Some vessels use a 100 mm mesh to allow for greater flexibility in their catch composition and to reduce discards. The Firth of Forth and Moray Firth support relatively clean *Nephrops* fisheries exploited with a mesh size of 80 mm. The UK fleet is subject to an MLS of 25 mm carapace length.

Historically, discarding of especially juveniles of bycatch species in the mixed fisheries has been high. Data on haddock discards (Figure 1) for two gears, *Nephrops* and whitefish light trawl, have been distorted by the very large 1999 year class, but by 2004, the proportion discarded had dropped below the level observed before 2000, suggesting a trend of improving selectivity, a change in discarding strategy in response to market conditions, poor recruitment, or a combination of some or all of these.

For cod, the proportion discarded (Figure 1) is less than for haddock because cod grow quickly through the sublegal size

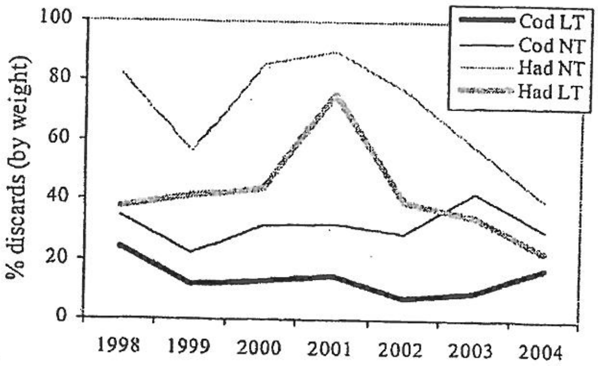

Figure 1. The percentage of the catch by weight of cod and haddock discarded in the Scottish light trawl (LT) and *Nephrops* trawl (NT) fleets operating in the North Sea, 1998–2004.

range, and fishers are less likely to highgrade cod than haddock or whiting (*Merlangius merlangus*) because of the higher price of cod even at MLS. The proportion discarded from *Nephrops* gears is again substantially greater than from light trawls, but the data reveal no major trend.

Technical conservation measures

Stock assessments indicate that North Sea *Nephrops* stocks are healthy and fluctuating about their long-term means (ICES, 2005), and protective measures have not been required. In the absence of a strong need to improve selectivity for *Nephrops*, the high level of whitefish discards has been the main driver for change in *Nephrops* gear design since the 1980s. Table 1 presents MLS, maturity, and selectivity information for cod and haddock in the inshore and offshore fisheries for two types of gear. For cod, the length at 50% maturity is well above the 50% retention length in *Nephrops* trawls of 80 mm mesh, although there is evidence that, in the past three decades, cod and haddock have matured earlier inshore where fishing pressure may have been greater (Yoneda and Wright, 2004; Wright, 2005).

Calls for action on discard levels came not only from national and EU managers, but also from the whitefish fleet, because they linked such discarding with the worsening state of their target stocks. This pressure led, in July 1991, to unilateral measures being taken by the UK. Square-mesh panels and other constraints on codend design were introduced with the aim of releasing more juvenile roundfish (haddock, whiting, cod). Gosden *et al.* (1995),

Table 1. Comparison of MLSs, lengths and age at which 50% are mature (L_{50}^{m} and A_{50}^{m}, respectively), and 50% retention length (L_{50}^{r}; from Anon., 2003, Appendix 5) of typical commercial codends currently used in the *Nephrops* and whitefish fisheries (80 and 120 mm).

Species and capture area	MLS (cm)	L_{50}^{m} (cm)	A_{50}^{m} (Y)	L_{50}^{r} (80 mm) (cm)	L_{50}^{r} (120 mm) (cm)
Cod inshore	35	36	2.7	23.4	38.8
Cod offshore	35	48	2.9	23.4	38.8
Haddock inshore	30	23.8	~2	20.9	34.7
Haddock offshore	30	27.3	~2	20.9	34.7

however, found no evidence of a reduction in discard rate resulting from these measures and suggested that the panel was not in the most effective position.

The revision of the technical regulations contained in EU Reg. 850/98 and brought into force in January 2000 did not address this issue of panel position. In the UK, industry and government agreed on additional unilateral measures to increase panel mesh size to 90 mm, and to reduce twine thickness to 4 mm single twine. In January 2002, further EU measures aimed at enhancing cod recovery were imposed on the *Nephrops* fleet. In the North Sea, MMS was increased from 70 to 80 mm, and the number of meshes around the circumference was limited to 120 for 80–89 mm mesh codends. These initiatives indicated a willingness by all parties to improve the selectivity of *Nephrops* gears.

The 2006 EU effort regulations (Reg. 51/2006) reduced the number of days at sea for the *Nephrops* fleet by ~2 per month as a further measure to limit fishing effort on cod. The North Sea Regional Advisory Council has proposed to offer an incentive in this fishery for the use of the more selective 95 mm codend (currently 80 mm) with a 120 mm square-mesh panel (currently 80 mm) in exchange for two additional days at sea per month (matching the reduction they had suffered from the previous year). The logic of this proposal was that the quota for *Nephrops* should not be curtailed (particularly because the TACs had risen), if mortality on cod could be reduced by other measures. However, the proposal was initially turned down in December 2005, partly because the information available was insufficient to quantify the effect of this new gear on cod selectivity for all EU fleets. The measure was subsequently approved at the December 2006 EU Council of Ministers meeting, and has now been incorporated into legislation.

Effect of effort management

In 2001/2002, more Scottish vessels, in particular twin-riggers in the Fladen area, started using voluntarily codends of mesh size larger than the prescribed 100 mm, to reduce discarding of whitefish. Based on information from *ad hoc* surveys of commercial codend usage, Ferro and Kynoch (2005) showed an increase in selectivity in Scottish twin-rig *Nephrops* gears during the first half of 2003. However, this improvement was short-lived because new effort regulations (EU Reg. 2341/2002) imposed a maximum of nine days at sea per month for trawlers using mesh >100 mm, whereas the 70–99 mm mesh fishery continued to be allowed almost unrestricted fishing (25 days per month). The reasoning behind this move was that the larger-mesh fishery represented the main component of cod mortality. In circumstances where cod recovery was the overriding priority, there was less need to limit effort in the smaller-mesh fisheries. At the time, the high discard rates of other species did not attract notable managerial attention. Remarkably, not only were the smaller-mesh fisheries allowed more days at sea, they were also allowed a larger bycatch limit for cod of 20% (by total volume of the catch) compared with the 5% limit for the fisheries using 120 mm mesh.

As a consequence, the twin-rig *Nephrops* trawlers changed back from >100 to 80 mm mesh to preserve their days at sea. With *Nephrops* densities high in many areas and fish quota suppressed, the incentive to highgrade and to land fish illegally increased. By comparison, management in the Skagerrak/Kattegat (EU Reg. 51/2006) encourages the use of more selective gear in the local *Nephrops* fisheries. Whereas just 103 days at sea are allowed when traditional 90–99 mm mesh gear is deployed, days at sea are unlimited if a 70–89 mm square-mesh codend and grid are used to eliminate all large whitefish. Such a regime tends to promote a clean *Nephrops* fishery, whereas the Fladen fishery remains a mixed fishery with up to 70% of the catch being other species. Maintaining viable mixed fisheries requires novel management, if multiple aims such as reducing whitefish discards and reducing mortality on marketable cod are to be met simultaneously.

Case 3: fisheries for walleye pollock in the eastern Bering Sea

Management frameworks

In Alaska, groundfish fisheries within the US EEZ are managed under two fishery management plans (FMP), one covering the Gulf of Alaska and the other the Bering Sea and Aleutian Islands (BSAI) region. In both regions, species-specific TACs for walleye pollock (*Theragra chalcogramma*) are established annually and are apportioned by season, area, and gear type. Catches (including discards) are monitored through daily observer reports and landing reports from processing plants. Heavy reliance on observer data is supported by a requirement for partial or full observer coverage (depending on vessel size). Conservation and management measures have a goal of reducing bycatch to the lowest practicable level and to minimize mortality of the bycatch if it cannot be avoided.

Bycatch is managed through a complex set of regulations including TAC set-asides to support bycatch requirements for target fisheries, as well as maximum retainable bycatch allowances that may constrain target fisheries as the overall TAC of a bycatch species is approached. Certain bycatch species are designated "prohibited species" (PSC), and this includes all salmonids harvested in the region, Pacific halibut (*Hippoglossus hippoglossus*), and commercially important species of crab. Retention of PSC is prohibited, and regulations require fisheries to be curtailed or relocated when the bycatch of these species exceeds specified levels.

The target fishery for walleye pollock in the BSAI is among the largest single-species fisheries in the world, the annual catch exceeding 1 million tonnes since the mid-1980s (Ianelli *et al.*, 2005). All fishing is conducted by trawlers. The fleet includes catcher vessels (CVs) delivering their catches to onshore or floating processor plants, and catcher/processors (CPs) processing their catches at sea. Although bycatch rates in the fishery have always been relatively low, small percentages can represent large quantities. The North Pacific Fishery Management Council (NPFMC) has taken several actions during the past decade to reduce bycatch.

We consider three factors (management measures and/or operational developments) that have influenced the efficiency of the fishery for walleye pollock in the BSAI and contributed to overall reductions in bycatch.

Progression from non-pelagic/pelagic to pelagic-only trawl gear

Historically, walleye pollock were harvested with non-pelagic (demersal) and pelagic trawls. Demersal fishing, however, had been discouraged to reduce bycatch and impact on the seafloor. Before implementation of the requirement to harvest pollock with pelagic gear (BSAI FMP Amendment 57), the National Marine Fisheries Service (NMFS) twice allocated the TAC among pelagic and non-pelagic gear types: once in the early 1990s, and again in 1999 when the entire pollock TAC was allocated to pelagic gear in anticipation of the approval of

Amendment 57. The NMFS, however, had terminated the temporal use of non-pelagic trawls on many occasions when PSC limits for crab and halibut were exceeded. During the 1990s, these limits were decreased, encouraging the fleet to adopt pelagic trawling (NPFMC, 2000). Therefore, although all directed fishing for pollock with non-pelagic gear was finally banned, earlier management action had encouraged a steady progression towards this goal.

To discourage deploying pelagic gear on the seabed, regulations implementing Amendment 57 limit the number of crab on board at any time; fishing on-bottom is not expressly prohibited.

Pollock and cod discard restrictions

In January 1998, Amendment 75 of the BSAI FMP was implemented. This required all vessels fishing for groundfish to retain all pollock and Pacific cod (*G. macrocephalus*), and to establish minimum standards of utilization, prohibiting codend bleeding (releasing fish into the water from the codend before the net is brought on board) or at-sea discarding of cod.

American Fisheries Act

The American Fisheries Act (AFA) of 1998 mandated significant changes in management of the BSAI fishery for walleye pollock. After setting aside a portion of the pollock TAC for the community development quota programme (requiring a proportion of the TAC for each groundfish species to be allocated to specified Alaska Native Communities under Federal Regulations) and for bycatch needs in the non-pollock groundfish fisheries, the regulations divided the remaining quota among three sectors. Within each sector, fishery cooperatives were established.

As a direct result of AFA implementation, the fleets consolidated, and latent capacity was reduced. Moreover, elimination of the race for fish encouraged the fleet to work collectively on strategies to reduce bycatch, especially in situations where high bycatch levels might restrict fishing opportunities or otherwise increase the costs associated with harvesting. Cooperative and intercooperative agreements allowed the fleet to respond collectively and effectively to challenges, such as the implementation of strategies to comply with mitigation measures related to the listing of the Steller sea lion (*Eumetopias jubatus*) and a programme that curtails fishing in areas when salmon bycatch rates are excessive (Karp *et al.*, 2005).

It is important to realize that the regulatory environment is complex and that this constrains our ability to establish cause-and-effect relationships between specific management actions and changes in fishing behaviour and catch composition.

Changes in target and bycatch composition

We examined changes in catch and bycatch composition for a group of 20 CPs that have remained active in the fishery since 1990. Although some differences in performance of the CV and CP components of the fleet are likely, overall trends are similar. Overall catch and catch composition is available for all years, but information on the species composition of discards has only been collected since 1997.

The progression from a two-gear to a one-gear fishery in terms of catch composition is illustrated in Figure 2a. Cleaner pollock catches are easier to achieve with pelagic gear, and the proportion of bycatch in non-pelagic gear varied markedly among years. Also, the proportion of bycatch taken by pelagic gear decreased steadily and levelled off at <2% post-2000.

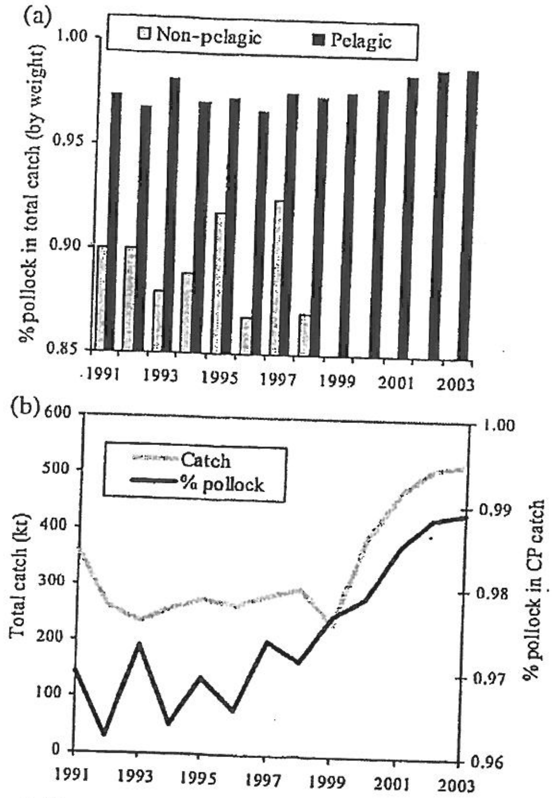

Figure 2. Eastern Bering Sea fishery for walleye pollock: (a) percentage of pollock in aggregate annual catches during targeted hauls of 20 CPs using pelagic gear or non-pelagic gear; (b) total pollock catch and the percentage of pollock caught during targeted hauls of 20 CPs.

Discards of pollock in this directed fishery have decreased steadily since 1997. Between 1997 and 1998, the discard rate for pollock dropped from 3.7 to 0.9%, with small reductions every year. Discards of Pacific cod taken in the fishery declined markedly between 1997 and 1998 (11.7 to 6.8%) and steadily since then (dropping to 0.4% by 2003). During the same period, the total catch of pollock taken by this group of CPs increased steadily (Figure 2b). Bycatch has decreased markedly since 1999, although overall catches have continued to increase. Non-pelagic trawling was prohibited after 1998.

Discussion

The Norwegian and Alaskan case studies present clear examples that restrictions on commercial practice provided incentives for fishers to accept the use of more-selective gears. Both countries also implemented discard bans (or full retention) and bycatch management plans. Regulatory authorities provided rules that determined whether fishing was permissible based on predetermined "acceptable" bycatch proportions, whether consisting of fish below minimum size or bycatch species. In Norway, the system of temporarily closing areas coupled with minimum catch-composition restrictions had the greatest influence on fishers' behaviour and the uptake of more-selective fishing technologies.

Alaskan fishers voluntarily reduced their reliance on demersal trawling, and changed their fishing patterns to stay within the regulatory boundaries. Clearly, the incentive was the prospective closure of highly productive pollock fishing areas when salmon bycatch thresholds were reached. The result is an industry-managed programme that shares bycatch information collected by observers and enforces agreements within and between cooperatives, requiring vessels to avoid areas with a high salmonid bycatch (Gauvin *et al.*, 1996; Karp *et al.*, 2005; Gilman *et al.*, 2006).

In both cases, the industry was faced with choosing between the lesser of two evils: alter strategy and adopt more selective fishing techniques or face the underutilization of resources and substantial economic losses. When managers eventually mandated the use of more selective gears, implementation was facilitated because industry had been closely involved in the formulation of the solutions.

The reduction in mesh size associated with the North Sea mixed fish/*Nephrops* fleet probably could have been avoided if they had not been subjected to regulatory controls aimed at another fleet, which happened to use the same mesh size. This implies that the categories used for defining fleets were too crude. Therefore, it was not possible to distinguish between the two, or at least to manage the two independently.

There is a need to improve the selective characteristics of the fleets targeting *Nephrops*, because the correlation between codend mesh size and minimum fish size is poor (Graham and Ferro, 2004). CEC (2004) suggests that by either adjusting MLS to match selectivity or, conversely, adjusting MMS to better reflect MLS, there could be a solution to reducing discarding. Unfortunately, the latter is not practical in multifleet fisheries where different mesh sizes are used, because this would require a different MLS for each fleet segment. Readjusting an MMS to an MLS may be suitable in some cases, but not if a small mesh size is needed to retain an important catch component. Therefore, there is a need in mixed fisheries to improve selectivity by use of mechanisms in addition to codend mesh size.

Could the Alaskan and Norwegian approaches be utilized to encourage fishers to use better techniques that would result in a reduction of discards and catches of species in need of protection? In cases where fishers know where and when to fish with low discarding of bycatch, specified bycatch limits and observers appear to be management measures, particularly where discarding is relatively infrequent at known times of year. However, if catch composition cannot be predicted with certainty, the use of species-separating gears may be the only option. Where the target species is sufficiently abundant to provide an economic return by itself, the solution may be to create a clean, single-species fishery by designing a gear that lets most bycatch species escape. If the bycatch is an essential component of the landings, a gear must be developed to separate the key species or groups of species so that appropriate selection mechanisms can be applied to each. Although a gear-design solution is unlikely to be 100% effective, it may be more acceptable to fishers than closure of large areas of traditional fishing grounds, and therefore raise less opposition. Regulations can specify the obligatory use of a gear in the area as an alternative to closure.

The use of bycatch quota, or caps, to limit fishing mortality generally depends on the availability of high-resolution, real-time data. However, the cost-effectiveness of observer schemes depends on fleet structure. Covering the North Sea fleets is unlikely to be feasible, because they include a large number of relatively small vessels. The Norwegian system of protecting juvenile fish relies on catch monitoring, but not on full observer coverage. It may be possible to introduce such systems into EU fisheries because a monitoring framework is already in place. Under the EU data-collection regulations (EC 1639/2001, amended by EC 1581/2004), member states are obliged to monitor the rate of discarding in all commercial fisheries. The data are currently used principally for assessment purposes, to provide better estimates of population parameters. A modified scheme could identify the degree of discarding on an appropriate spatial and temporal scale, and by fleet. Monitoring of commercial catches in these sensitive areas could then be used as a mechanism to trigger area closures, as was done in Norway.

Adopting the principle of temporary area closures allows fishery management to become less prescriptive and more incentive-based. Complex legislation specifying detailed construction characteristics of gears might be substituted by suitable triggers for closure, and a range of specified gears may be described in a more general sense to comply with output measures. The use of output measures is common in other industries, such as those generating industrial pollution. In a fisheries context, enforcement agencies monitor the catch composition rather than the gear, and determine whether target levels are met. Gear technologists could assist with the development and formal testing of gears under commercial conditions, fostering science/industry collaboration and promoting the commercial uptake of the gear.

Realistically, fisheries exploiting a limited number of species, such as the Alaskan and Norwegian examples, are more amenable to this approach than fisheries in which many of the species caught represent an economic return and the mix is highly variable. In such cases, a more pragmatic approach is called for, perhaps defining catch limits on just a few key species and providing economic incentives to encourage the use of more-selective fishing techniques. Investigations of economic incentives have been limited and tended to focus on the transfer of techniques, such as game theory to model and predict fisher or fleet behaviours in response to changing circumstances (Kennedy and Pasternak, 1991; Krawczyk and Tolwinski, 1993; Mazalov and Rettieva, 2003). At a microlevel, consideration has been given to access rights, tax incentives, and grant assistance. Detailed investigations of the incentives driving the behaviour of real fishers (as opposed to model fishers) are also rare, but they do reveal relevant information (MacMullen, 1998; Anon., 2002).

Anon. (2002) studied 26 métiers in fishing areas southwest of the UK, in an effort to understand the factors motivating fishers to target and retain, or discard, certain species, and to relate this to the prevailing management and market conditions. Among the findings was that discarding practices were most closely related to economic values, and that there were clear incidences where these economic influences were stronger than those of fishery regulations. Sometimes fish smaller than the MLS were retained because of good local market demand, and in other cases, fish greater than the MLS were discarded because of low demand for certain size grades. When the MLS was decreased for one species, one fleet immediately retained fish that matched the new legal size, whereas another, working on the same grounds, did not. Although both ultimately supplied the same customers, the latter fleet worked through a market that paid only an "all in" price and penalized the landing of smaller fish. By plotting retention lengths by crew members sorting on deck against market prices, it was clear that individual fishers exercised judgements based on market value and subsequent labour requirements. When skippers or mates were also on deck, the behaviour changed.

Anon. (2002) concluded that, in most cases studied, economic influences were paramount and efforts to reduce discarding that failed to take these influences into account were unlikely to be successful. Economic factors also influenced fishers' perceptions of which stocks were priorities for conservation. A pragmatic interpretation of these observations should also take into account the points raised above. Many métiers studied by Anon. (2002) were not subject to any systematic observer regime at sea, and often very little at the point of landing. Even where this was the case, relatively weak sanctions and a lack of incentives produced behaviour that typically sought short-term economic advantage over any consideration of longer-term advantage.

All three case studies demonstrate that maximizing fishing opportunities within specified constraints tends to be a more powerful incentive to fishers than medium- to long-term aims of improving sustainability. That is not to say that such goals are unimportant, but ensuring short-term economic viability tends to override longer-term aims. Therefore, the tendency to maintain fishing opportunities has to be linked with the longer-term aim of improving sustainability through reducing discards and/or bycatch. In the first instance, it is necessary to define the limits of the quantities of fish of sublegal size or bycatches that are acceptable. It is also necessary to shift the monitoring, surveillance, and control onus from landings to catches. By providing the correct incentives and defining realistic targets, it should be possible to reduce unwanted bycatch and discards.

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