The role of technical measures in European fisheries management and how to make them work better

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Technical measures such as gear restrictions are commonly used in European fisheries management. Many of the measures are aimed primarily at protecting juveniles. Although they are assumed to provide both biological and economic benefits, proper evaluation of their effects relative to what is intended is often not possible because of a lack of adequate follow-up studies. Moreover, technical measures usually are used in conjunction with other management measures, which greatly complicate the analysis. We describe the principal factors affecting their effectiveness to find the approaches that may help to improve performance. Many regulations are enforced inconsistently, and their implementation is often less restrictive than originally intended. Moreover, trying to solve one problem frequently creates new ones. The successful use of technical measures appears to depend largely on their acceptance by industry. Measures that increase costs or reduce earnings are unattractive, so if short-term effects are not accounted for, the potential long-term gains may never materialize. Successful management actions have addressed these problems. Although technical measures may conserve resource, particularly to supplement a broader management policy, new regulations should be planned with great care, and any measures should be tested properly before implementation.

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Introduction

Technical measures aim to control various aspects of fishing operations, ranging from gear restrictions to bycatch limits and closed areas. They represent an important toolbox in the management policy of many fisheries around the world, including Europe. One of the main reasons for imposing technical measures, particularly those related to gear restrictions, has been to create conditions that minimize the capture of juveniles of commercially important species or incidental catches of non-target species (CEC, 2001).

In global terms, the Northeast Atlantic represents an area with relatively high rates of discarding (average 13%), accounting for about 22% of the world's total discards (FAO, 2005). In biomass, this corresponds to a total wastage of about 1.3 million tonnes annually. The North Sea bottom-trawl fishery alone is estimated to account for more than half this amount (FAO, 2005). Consequently, research on technical measures that can help reduce bycatch and discards has been a focus of many fisheries institutes in Europe. Over the past decade, the European Union (EU) has contributed about €8 million annually to more than 400 projects on gear selectivity, discard reduction, and quantification of impacts of fishing gears on habitats (Fischler, 2004). This research is reflected in continuous changes in EU legislation.

Gear modification to improve selectivity through a variety of sorting devices has been proven to reduce bycatch and discard rates (Valdemarsen and Suuronen, 2003; ICES, 2004). Many prescriptions and restrictions have been introduced through legislation, and some devices are being used on a voluntary basis. Nevertheless, with few apparent exceptions (OECD, 1997; Halliday and Pinhorn, 2002; Cook, 2003; Pascoe and Revill, 2004; Pawson *et al.*, 2005), little attempt has been made to assess the effects of prescribed devices in biological and economic terms. Quite often, the fishing industry has been sceptical about their effectiveness, because the science behind the initiatives is perceived as theoretical and out of touch with the harsh reality of commercial fisheries. Although some progress has been achieved recently in reducing bycatch and discards through changes in fishing practices (Hall *et al.*, 2000; FAO, 2005), the total quantities discarded are still very large in many fisheries.

We try to pull together lessons learned from the technical measures introduced in European waters, focusing on gear-related regulations introduced under the EU Common Fisheries Policy (CFP), to evaluate their effectiveness, to inform fisheries management agencies how their contribution to sustainable development might be enhanced, and to identify important issues requiring further research.

Historical perspective

Although national mesh-size regulations in Europe date back to the 16th century (Burd, 1986), a comprehensive EU Regulation introducing technical measures was issued only in 1980, covering the fishing grounds from the Kattegat to the Bay of Biscay. In 1986, after several revisions, the regulation was extended to the Atlantic fishing grounds off the Iberian Peninsula. In 1992, a modest increase in minimum mesh and other measures were adopted to improve gear selectivity in the groundfish fishery. North of 48°N, the legal minimum mesh size (MMS) in towed gears was increased from 90 to 100 mm. However, as usual within the CFP, several derogations were granted, permitting the use of smaller mesh sizes. Such derogations usually also restrict landings of target and/or bycatch species, so creating additional discard problems. No increase was implemented for the southern region, where the standard mesh size in towed gears remained 65 mm.

Measures enforced in the 1980s and early 1990s did not meet the expectations (CEC, 2001). Catches and discards of juveniles were not reduced, and compliance was no better than before. New elements have been introduced in the legislation regularly, and include square-mesh panels inserted in the codend, prohibition of the use of double netting in codends, and an MMS for fixed gears. During the late 1990s, maximum twine diameter and maximum codend circumference were regulated in some key fisheries, and the mesh size in North Sea demersal roundfish fisheries was increased to 120 mm. However, many trawl fisheries were still allowed to use a smaller mesh size because of derogations. Despite attempts to harmonize mesh-size regulations in the Atlantic area and to make the regulations easier to enforce, discards of juvenile fish have remained a huge problem, and the changes in legislation appear to have had a much smaller effect than envisaged (CEC, 2001).

Technical measures in the Baltic Sea have been covered by regulations taken by the International Baltic Sea Fishery Commission (IBSFC) until 2006, when the commission was dissolved. Because the EU had been a Contracting Party, it was bound to implement the measures taken by the IBSFC. The measures typically defined mesh sizes and other aspects of gear construction, periods, and areas within which specific types of gear were prohibited, and minimum landing sizes (MLS) of some species. In 2006, an attempt was made to keep legislation consistent across the Baltic and other community waters.

Conservation of fishery resources in the Mediterranean has traditionally been based on regional restrictions of fishing days and the traditional technical measures. In the early 1990s, the area covered by the CFP was extended to include the Mediterranean Sea. The implementation of existing regulations, however, has not yet been satisfactory. The fish caught are getting smaller, and discarding is widespread (GFCM, 2006). A series of new measures is being designed to enhance sustainable exploitation. Effort regulation would remain the main instrument, reinforced by stricter technical measures and by strengthened control and enforcement.

New types of regulations to reduce bycatch are constantly being initiated. In 1998, a progressive ban was agreed on the use of driftnets for the capture of tuna by EU vessels in both the Atlantic and the Mediterranean, and this is expected to have a major conservation effect on populations of small cetaceans and other vulnerable species. In 2004, the EU introduced a ban that phases out the use of driftnets in the Baltic Sea by 2007, to protect the local harbour porpoise population. This ban has a major impact on the commercial salmon fishery because driftnets have dominated the gear used in the area for the past 30 years. More recently, the use of real-time closures of areas with dense concentrations of young fish, experiments with the introduction of a discard ban, and economic incentives to encourage fishers to use more selective gears (e.g. by giving them a bonus of extra fishing days) have been considered.

Problems encountered

Here, we describe and discuss some examples of the problems associated with technical measures currently applied to European fisheries, with a focus on gear regulation, to illustrate the principal factors influencing their performance.

North Sea brown shrimp fisheries: bycatch of juvenile flatfish

The brown shrimp (*Crangon crangon*) fishery is important economically all around the North Sea (Pascoe and Revill, 2004). Although the target species shows no sign of overexploitation, a major problem is the substantial bycatch of juveniles of commercially important fish species, which are discarded. European legislation required that all vessels engaged in these fisheries in Community waters should have sieve nets or separator grids fitted into their trawls by 2002 (Revill and Holst, 2004) to reduce bycatch and therefore discarding.

Revill (2001) assessed the likely outcomes of the use of selective trawls in terms of the benefits to fish stocks and their future landings. The expected effectiveness varied considerably between fleets. In the Wadden Sea, most shrimp vessels reportedly used sieve nets on a voluntary basis already by late 1990s. However, despite the widespread use of sieve nets, discarding of small flatfish remained a problem: in that region alone, an estimated 880 million juvenile plaice were discarded in a single year (1996/1997), resulting in a predicted loss of >10 000 t of plaice landings annually. The assessment indicated that prescription of selective trawls was unlikely to precipitate a major effect, if any, in the Wadden Sea region because neither sieve nets nor grids are effective in selecting out the small 0-group plaice dominating those fishing grounds. The situation in UK and Belgian fisheries and the Dutch fisheries in the southern part of Dutch coastal waters was quite different, with benefits to fish stocks and future landings anticipated from the introduction of selective trawls. The reason for this difference is mainly that the fish caught in those regions are generally larger than those caught in the Wadden Sea, meaning that they are more effectively selected out by sieve nets and grids. Clearly, the same technical solutions are not applicable in all regions.

Pascoe and Revill (2004) noted that, in complying with the new gear regulations, the catch rate of the target species (brown shrimp) was likely to be reduced. Nevertheless, they estimated that the introduction of uniform gear restrictions would have only minor effects on the profitability of the brown shrimp fisheries as a whole, but could result in a transfer of benefits from some countries to others. Moreover, the long-term benefits to finfisheries were expected to more than offset the costs for the shrimpers, resulting in an overall net benefit.

North Sea mixed-species demersal trawl fishery: increasing mesh size

During the past two decades, the MMS in the demersal trawl fishery in the North Sea (excluding the beam-trawl fishery for flatfish) and surrounding waters has been increased in several steps from 90 to 120 mm, in combination with many other management measures. Recent assessments reveal that several of the roundfish stocks targeted are in a poor state and that the fishery is not sustainable. Large numbers of haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) and substantial quantities of cod (*Gadus morhua*) are discarded annually (ICES, 2005), most below the MLS (whiting, 23 cm; haddock, 30 cm;

cod, 35 cm). Garthe *et al.* (1996) estimated the annual fishery discard of roundfish in the North Sea to be ca. 260 000 t, equating to about 20% of the total North Sea demersal catch.

There are several reasons for the extensive discarding in this fishery. One problem is that fishers have to discard excess catches when the quota for a particular species in a mixed-species fishery has been exhausted, as well as those below MLS (regulatory discards). For many key species, the authorized mesh sizes remain far too small for the effective protection of their juveniles. Introducing a larger MMS might help, but this could also reduce the yield-per-recruit for some species below the maximum sustainable level (Macer, 1982; Graham and Kynoch, 2001; Graham *et al.*, 2004). Given the present size composition of haddock and whiting stocks in the North Sea, these species would largely be eliminated from the catches if the mesh size were to be adjusted to be optimal for cod. Prescribing one mesh size to catch these species inevitably results in extensive discarding or large (short-term) losses for the industry.

This case demonstrates the problem faced in almost any mixed-species trawl fishery. To improve the situation, the gear needs to be designed to separate the different species first by some species-selective device, and then to sort each unit in a size-selective device. That would not be easy to design and accomplish and would require substantial research effort. Furthermore, compliance with technical measures has remained problematic, as in many other demersal trawl fisheries (Ferro and Graham, 2000). Fishers tend to adopt codend-design features that reduce rather than enhance selectivity, and these may largely negate increases in mesh size. It is relatively easy to modify gears, by both legal and illegal means. Technical measures have to be consistent with clearly stated management objectives to which fishers can commit themselves, and they also have to be enforceable.

Northeast Arctic cod trawl fishery: no evaluation

In 1997, the sort-X grid system became mandatory in the Barents Sea to enhance sorting by size in the demersal trawl fisheries for northeast Arctic cod. Assessing the effects of changes in fleet selectivity, Kvamme and Frøysa (2004) showed by simulation that there would be substantial gains, in terms of both stock size and catches, from increasing the mean retention length by 5–8 cm relative to the estimated value of ~47 cm prevailing before 1997. Catches of 3- and 4-year-olds would decrease, but catches of 6-year-olds and above would increase within a few years. Because such cod attain maturity when they are 6–12 years old (65–105 cm), the proposed increase in retention length would largely affect immature fish. Although Kvamme and Frøysa (2004) pointed out that such a change in selectivity would lead to more efficient exploitation of the stock's growth potential and that more fish would have a chance of maturing and spawning, no information exists as yet whether the introduction of the grid has had any real effects on stock and catch.

Baltic cod demersal trawl fishery: compliance

Several changes in codend mesh size and codend construction were introduced in the Baltic cod trawl fishery during the past decade to improve the exploitation pattern (Suuronen and Tschernij, 2003). Simulations by Kuikka *et al.* (1999) suggested that the average yield could be increased by 30–40% by increasing the codend mesh size from 120 to 140 mm, and by decreasing trawl effort by 20%. However, those authors did not fully assess several sources of uncertainty. For example, cannibalism might increase more than they had assumed, so reducing recruitment to the fishable stock; density-dependent effects could lead to retarded growth; cod may move to other areas; and the mortality of escapees may not be zero (Suuronen *et al.*, 2005).

In reality, there has been no measurable positive development after the introduction of more selective trawls in this fishery (ICES, 2005). This is at least partly because the short-term effects were not taken into account in the management decisions. The simulations made by Tschernij *et al.* (2004) suggested that, when the mesh size of a Bacoma panel (Madsen *et al.*, 2002) is increased from 105 to 120 mm, the overall loss of fish of marketable size in the catches during the first months (keeping the effort constant) would be around 40–50%. If fishers decided to try to compensate for their losses by fishing harder, effort would have to be increased 55–90%, which would seem impossible. Perhaps more likely, they could try to circumvent the regulations by intentionally decreasing the selectivity of their gear. In fact, widespread gear manipulation, legal and illegal, was observed in 2002 and 2003 after the introduction of the 120 mm Bacoma panel (Suuronen and Tschernij, 2003): fishers were not able to cope with such large losses in catch, and overall fleet selectivity did not improve. In response, the MMS of the Bacoma panel was subsequently reduced to 110 mm in September 2003, which appears to have led to substantially better compliance, at least in Swedish and Danish fleets.

This example demonstrates that, even when a fleet targets one species almost exclusively, an effective increase in fleet selectivity may require a complex set of actions: gears will be manipulated and rules will be circumvented if the losses to individual fishers are too large. Therefore, short-term effects should be addressed in management plans for introduced measures to be effective.

Mediterranean multispecies trawl fishery: enhancing yield

Conservation of fishery resources in the Mediterranean Sea is based largely on technical measures aimed at protecting juveniles. In most countries bordering the Mediterranean, the present legal MMS in demersal trawl codends is 40 mm, which does not allow the effective escape of undersized fish (Bahamón *et al.*, 2006). Experiments suggest that selectivity can be substantially improved by relatively simple modifications such as square-mesh codends with a proper mesh size or sorting-grid installations with appropriate bar spacing (Stergiou *et al.*, 1997; Sardà *et al.*, 2004, 2005; Bahamón *et al.*, 2006; Guijarro and Masutti, 2006).

To improve the overall exploitation pattern, the EU and the General Fisheries Commission for the Mediterranean proposed a universal 40 mm square-mesh codend in all demersal trawl fisheries (to be enforced in 2008). For many commercial species, this measure should allow a substantial improvement in selectivity over the present situation, although losses of some species through the meshes could be relatively high (Bahamón *et al.*, 2006; Guijarro and Masutti, 2006). The increase in average age-at-first-capture is expected to lead to higher long-term yield for most species, even if an optimum may not be achieved for all (Bahamón *et al.*, 2007). Clearly, a 40 mm square-mesh codend cannot solve all problems in these multispecies fisheries, but it could help markedly to improve exploitation patterns. To guide further regulation, development of species-selective gears should have a high priority in research. However, any improvement in the stock situation depends ultimately on enforcement, and compliance with existing rules has to improve dramatically.

Haddock and Baltic herring: accounting for escape mortality

Needless to say, virtually all roundfish discarded from a vessel deck after sorting fail to survive. However, fish escaping from a trawl codend during the haul may not always survive either (Suuronen, 2005). For haddock, estimates of escape mortality range from 10 to 50% (Soldal *et al.*, 1993; Sangster *et al.*, 1996; Ingólfsson *et al.*, 2002). There are strong indications that the smallest haddock are the most sensitive to capture and escape-induced stress and injury (Ingólfsson *et al.*, 2002; Ingólfsson, 2006). Cook (1998) showed that the mortality of North Sea haddock caused by escape-induced stress and injury peaks at age 2, representing about 40% of the mortality caused by fishing at that age. Breen and Cook (2002) demonstrated that including discard mortality significantly increased the estimates of fishing mortality, particularly for ages 1 (94%) and 2 (63%). Including escape mortality (assuming that 25% of escaping fish die) increased fishing mortality by 38 and 7%, respectively. Therefore, compared with discard and "landings" mortality, escape mortality is a minor factor. Also, the relative importance of escape mortality decreases rapidly with age. Breen and Cook (2002) emphasized that the benefits of increasing the legal MMS is greatly reduced if a substantial proportion of the escaping fish die. They also emphasized that exclusion of escape mortality in the estimates of fishing mortality may introduce significant bias into the stock assessment process if gear-selectivity regulations were introduced.

In assessing the effect of escape mortality on Barents Sea haddock, Ingólfsson (2006) estimated that, at the present level of fishing mortality, the annual escape mortality at stock level would be about 3% for 20 cm haddock, declining with length to 1 and 0.3% for 30 and 40 cm haddock, respectively. This mortality corresponds to a removal of 6.5 million haddock, some 650 t. However, if fishing mortality were as high as in the North Sea, the effects of escape mortality would be substantially larger.

Kuikka *et al.* (1996) studied the impact of increased codend mesh size (from 20 to 36 mm) on the pelagic-trawl fishery for Baltic herring (*Clupea harengus*), incorporating an escape mortality of 85% (Suuronen *et al.*, 1996). Their results indicate that, under the conditions prevailing from 1974 to 1992, such an increase in mesh size would have led to reduced catches and a lower catch-per-recruit. The estimated reduction varied greatly, depending on growth rates and natural mortality. The calculations suggested that, to make an increase in mesh size profitable for the fishery in the long term, the survival of codend escapees would have to be increased to at least 80% (compared with the current estimate of 15%). Therefore, for species suffering high escape mortality, there may be no biological or economic justification for a mesh size increase.

Rahikainen *et al.* (2004) showed that more Baltic herring aged 0 and 1 die from escaping through the nets than are actually landed. Because escape mortality decreases as a function of age and size (Suuronen *et al.*, 1996), the impact on estimated recruitment and fishing mortality at age 1 is considerable, whereas the effect at age 2 and older is relatively small (at the present exploitation pattern). The adjusted fishing mortality at age 1 was more than twice as high as unadjusted estimates.

Clearly, unless the level of escape mortality is known, the benefits of changing selectivity can be massively overestimated. The problem of poor survival may be a common characteristic of many pelagic fish species (Suuronen *et al.*, 1997).

Discussion

The examples reviewed here suggest that improvements in resource conservation and discard reduction attributable to the legislative introduction of technical measures usually are smaller than that had been predicted or assumed before their implementation. However, it is often difficult, if not impossible, to separate the effects of specific management measures from the many other changes taking place in these fisheries and in the target stocks at the same time. Moreover, the continuous revisions of the regulations and the introduction of new ones make it virtually impossible to evaluate the specific effects of individual regulations. *Ex ante* studies appear more popular than *post hoc* evaluations, and few studies have actually been able to verify predicted effects using appropriate follow-up studies.

Nevertheless, the legal mesh sizes in many demersal fisheries remain obviously too small to protect juveniles and young adults effectively, and insufficient numbers of fish survive to replace the losses in spawning-stock biomass. It has also become increasingly clear in many fisheries that regulating gear selectivity alone is not sufficient to provide sustainable exploitation patterns, and also that the measures imposed may have unintended, negative effects. Regulation-induced discarding provides a clear example. In multispecies fisheries, no single mesh size suits all species, and any change may favour one species at the expense of another.

Although overall exploitation patterns may be improved, gear modifications generally make net construction more expensive, and modified gears are often more difficult to operate and maintain. Although this may cause reluctance among fishers to commit to such regulations, the short-term economic losses associated with selective fishing gears are a more important concern from the fishers' point of view. Broad acceptance and practical implementation may depend largely on the ability of the industry to deal with the losses. The potential economic costs and benefits of new measures need to be evaluated thoroughly before new regulations are issued.

Gear-related conservation measures are based traditionally on the assumption that fish escaping from fishing gears survive and live on to support the exploited population. For many commercially important fish species, there are currently no reliable estimates of post-capture survival, but the information collected indicates that escape-induced mortality may not always be negligible. Failure to quantify the biological impact of this largely unknown mortality can result in bias in evaluations, where mesh size changes are concerned. Escape-induced stress and injuries are undoubtedly influenced by many factors, such as fish size relative to mesh size, type of mesh (diamond vs. square), and fishing speed and filling of (and water flow through) the net (catch rates). Because especially the latter depends on the mesh sizes used, escape estimates for one particular configuration may not apply to another, and predictions remain extremely difficult. Nevertheless, one might expect that, in general, the use of larger meshes results in smaller catches, less blocking of the meshes, and possibly less injuries to the escaping fish.

MLS regulations are applied in many fisheries to protect smaller fish. The extent to which MLS achieves its objective of encouraging fishers to target larger fish has not been systematically evaluated. MLS regulations are often considered a necessary backup to MMS regulations, but there is no scientific evidence that they are an incentive to use larger mesh sizes. Rather, fishers may reduce their mesh size to ensure that no fish above the MLS is lost. The link between MLS, gear selectivity, and discarding rate is often poorly understood. The appropriate match between MMS and MLS is a particular problem in multispecies fisheries, because the MLS regulations in those fisheries often generate discard problems, rather than helping to resolve them. Without species-selective fishing technology, these problems cannot be solved effectively. MLS regulations may work better with passive gears, because size selectivity is better and fish released are often in a better condition after the capture process than fish discarded from active gears.

To conclude, effective implementation and enforcement of technical management measures can be extremely difficult, particularly in multispecies fisheries. Fishers may resist in a variety of ways, and they are capable of effectively sabotaging almost any management measure. Hence, a necessary condition for any successful introduction is industry support. Effective management should create incentives for fishers to change their behaviour, so that in the long run the entire industry can benefit economically from the use of fishing methods that reduce bycatch. In our view, technical measures, if properly planned and implemented, still have potential as supplementary measures for resource conservation, but their potential benefits have not yet been fully utilized.

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