Sustainable use of flatfish resources: solving the credibility crisis in mixed fisheries management

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Running head: a credibility crisis in fisheries management

Abstract

Most flatfish species are caught in mixed demersal trawl fisheries and managed by Total Allowable Catch (TAC). Despite decades of fisheries management, several major stocks are severely depleted. Using the Common Fisheries Policy (CFP) as an example, the failure of mixed fisheries management is analysed by focussing on: the management system; the role of fisheries science; the role of fisheries managers and politicians; the response of fisheries to management. Failure of the CFP management could be ascribed to: incorrect management advice due to bias in stock assessments; the tendency of politicians to set the TAC at a level well above the recommended level; non-compliance of the fisheries to the management regulations. It is concluded that TAC management, although potentially successful in single species fisheries, will inevitable lead to unsustainability in mixed demersal fisheries as it promotes discarding of over-quota catch or misreporting of catches, corrupting the basis of the scientific advice and increasing the risk of stock collapse. The failure of the TAC system in mixed demersal fisheries resulted in the loss of credibility of both scientist and fisheries managers, and undermined the support of fishermen for fisheries management regulations. An approach is developed to convert the TAC system into a system that controls the total allowable effort (TAE). The approach takes account of the differences in catch efficiency between fleets as well as seasonal changes in the distribution of the target species and can also be applied in the recovery plans for rebuilding specific components of the demersal fish community, such as plaice, cod and hake.

Key words: fisheries management, flatfish, CFP, mixed fisheries, effort management, catchability, TAC

Introduction

Flatfish are generally exploited by demersal trawl fisheries targeting a mixed bag of species (Millner *et al*., 2005; Wilderbuer *et al*., 2005; Munroe, 2005). Although the management systems used are diverse, most systems build upon total allowable catches (TAC) for individual species accompanied by technical measures such as gear restrictions, minimum mesh sizes, closed areas and seasons (Rice *et al*., 2005). Examples of effort management that attempts to regulate fishing mortality primarily by effort restrictions are scarce. Most effort management systems are based on some kind of capacity control or limiting the number of entries by issuing licenses, but this may only slow down the process leading to overexploitation rather than restrict fishing mortality (OECD, 1997). In line with the status of most commercially exploited fish stocks worldwide (FAO, 1995), many flatfish stock (38 out of 65) have been overfished at least during some period during their exploitation history (Rice and Cooper, 2003). The global decline in fish stocks has raised public concern and the reasons behind the failure of fisheries management are intensively debated (Pauly et al., 2002; Caddy and Seij, 2005; Garcia, 2005; Smith and Link, 2005). As the three main actors involved (fishing industry, management authority, fisheries science) all play a distinct role in the management process, failure may be related to imperfections in the system at any of these levels. Major issues are the scope for enforcement (Nielsen and Mathiesen, 2003), the management policy adopted and the quality of the scientific advice (EC, 2002). Whatever the underlying reason, the scientific advisors appear to have lost their credibility, exemplified by the accusations by fishers that assessments do not correspond to their daily experience, by the responsible authorities that the annual advice is inconsistent, and by academics or NGO's that fisheries scientists are too closely related to the management bodies or fishing industry to be able to give an impartial advice (Finlayson, 1994; Hutchings et al., 1997; see also Garcia, 2005; Smith and Link, 2005).

We review the situation in respect of success or failure of fisheries management as exemplified by the situation in Europe. We argue that sustainable exploitation in mixed fisheries cannot be achieved by single-species TAC because fishers may continue to fish after the TAC of one of the species is taken. As a potential alternative, we develop a method that allows TAC management to be converted into a system of effort management that may contribute to the rebuilding of depleted demersal stocks and rebuild the credibility of the entire management system, including the role of fisheries science.

The Common Fisheries Policy

The legal basis of fisheries management in the European Union is laid down in the Common Fisheries Policy (CFP), agreed upon in 1982 (Holden, 1994) and pursuing the ultimate objective of sustainable exploitation of renewable marine resources taking account of the integrity of the marine ecosystem as well as social and economic conditions (EC, 2002). The main instruments comprise stock-specific TACs agreed upon annually by the Council of Ministers, various technical measures (e.g., mesh sizes, gear and bycatch restrictions, closed areas and seasons), and since 1993 a 5-year multi-annual guidance program directed at reducing fleet capacity of individual countries. The CFP was agreed to be reviewed at 10-year intervals, and adapted if member countries would reach agreement to do so. It was not until the third cycle (2003-2012) that the CFP was modified to incorporate the possibility to regulate fishing effort by setting limits to the days-at-sea for specific fleets on an annual basis (EC, 2002). However, the use of effort regulation is restricted to recovery plans and the TAC still remains the basis for managing fisheries. The underlying reason why the EU originally opted for a TAC system with fixed shares based on historic catches of the member states was that such a system was envisaged to ensure 'relative stability' of the national fishing industries (i.e., all nations would suffer or profit equally from changes in TACs). This original objective is strongly adhered to by the member states, even though other economic developments have resulted in marked deviations owing to quota hopping and re-flagging of vessels (Hatcher *et al*., 2002).

The scientific basis for the TAC negotiations is laid by the stock assessments and catch forecasts provided annually by the International Council for the Exploration of the Sea (Rozwadowski, 2002; ICES, 2004). Stock status in terms of sustainable exploitation is compared to precautionary reference points for spawning stock biomass and fishing mortality derived from the empiric relationship between recruitment and spawning stock. This type of management advice relies heavily on reliable catch statistics, age compositions of the landings and recruitment estimates based on research vessel surveys. Depending on the status, the ICES advice comprises of a range of options that are consistent with sustainable exploitation within a single-species context.

The European Commission (EC) generally follows the advice and selects a particular option within the 'advised' range. Because of economic or societal concerns, the EC generally proposes the option that is on the borderline of being estimated by scientists as being 'sustainable'. These proposed TACs are not necessarily followed up by the Council of Ministers (the 'politicians'), sometimes leading in some years to a substantial discrepancy between the 'proposed' TAC and the 'agreed' TAC (Daan, 1997).

Quality of catch statistics

The quality of stock assessment is directly linked to the quality of the catch statistics and negatively affected by illegal or misreported landings as well as by discarding of under-sized as well as of over-quota fish. In mixed fisheries, discarding of under-sized fish can be substantial owing to the mismatch among the selectivity characteristics of the different species. In the beam-trawl fishery targeting sole, discard rates of plaice may be as high as 50% in numbers (van Beek, 1998; Pastoors et al., 2000), while their survival chance is less tan 5% (van Beek et al., 1990). Obtaining reliable stock-wide and fleet-wide estimates of discards is generally prohibited by the high costs of sampling at sea. While during one morning in the fish market two technicians may sample the total landings of several vessels after their weekly trip, they usually have to stay on board of a single vessel for the whole week to sample its discards at one particular location. Combining two data sets with completely different error sources, landings statistics being purposefully biased by fishermen's actions and discards statistics being affected by sampling limitations, does not necessarily improve the advice!

Discarding of over-quota catches is entirely legal under the CFP (Daan, 1997; Nielsen and Mathiesen, 2003; Hatcher, 2005) and can be expected under a TAC system (Anderson, 1994; Gillis et al., 1995), but is particularly difficult to quantify empirically. Using a dynamic state variable model of effort allocation and high grading in the Dutch flatfish fishery under a TAC system, Poos *et al.* (2006), showed that a reduction in the individual quotum for plaice (ITQ), the least valuable of the two target species, was compensated for by re-allocation of fishing effort from an area (central) with a high abundance of plaice and a low abundance of sole, towards fishing grounds (south) with a higher abundance of sole and a lower abundance of plaice (Figure 1). When the ITQ for plaice decreased further, the fleet could only continue fishing by discarding an increasing part of the plaice catch. At even lower ITQ for plaice, the fishery had to stop fishing because fishing was not profitable anymore. The model results are qualitatively supported by information from the fishing industry suggesting that high-grading may occur at the beginning of the year when catch rates of plaice are high and comprise of less valuable spent fish, and at the end of the year either when catch rates increase owing to the recruitment of a new year class or because quota become exhausted (Figure 1c). Although the extent of high-grading remains unknown, it is likely to affect age groups differentially. As a consequence, the impact on the quality of stock assessment may be severe, even when the amount discarded represents only a relatively small proportion of the annual catch. Owing to non-compliance, catch statistics may also be distorted by illegal (unallocated in ICES terminology; whether unreported or misreported) landings (Nielsen and Mathiesen, 2003; Hatcher, 2005). Unallocated landings have been substantial in the 1980s in both sole and plaice (Daan, 1997) and widespread underreporting has been reported recently from the fisheries for cod and haddock (ICES 2004).

Landings and effort statistics are recorded under the responsibility of national governments. Although their cumulative accuracy is of crucial importance, scientists have little insight in this matter. The basis is contained in logbooks to be filled in by skippers on a daily basis, which are collected when ships enter the harbour for landing their catch. Ships may be visited at sea by inspection services or their landings may be compared to their logbook data. If discrepancies are found, the logbook data are corrected. However, the essential piece of information required to evaluate the quality of catch statistics is the sampling intensity for inspection purposes as well as the average discrepancy between logbook catch and actual landings, because this would allow at least some estimate of the total over-quota landings. Although this information is not made publicly available, informal contacts with the fishing industry often suggest major discrepancies between reported and actual landings. For some fleets, it has been possible to estimate the rate of underreporting or misreporting based on confidential information from the industry, and the 'unallocated landings' category has been corrected accordingly. However, the confidential nature of such information prohibits detailed descriptions of the raising procedure used and the use of 'unallocated landings' has not contributed to the transparency of the assessment and the formulation of advice.

Quality of the scientific advice

The analysis of the historic performance of stock assessments reveals both the uncertainty of the estimates of stock size and fishing mortality in the most recent year, as well as the bias that may occur during certain periods (Figure 2). Uncertainty may be due to bias and measurement error in the input data, as well as to variability in fleet dynamics (e.g. catchability) and stock dynamics (e.g. growth rates) (Shepherd, 1988; Hilborn and Walters, 1992; Patterson et al., 2001). Bias may further be due to the analytical technique used (Mohn 1999). Although models that assume the catch-at-age matrix to be uncertain (Deriso et al., 1985; Kimura, 1986; Patterson and Melvin, 1996) are considered superior to models such as Extended Survivor Analysis (Shepherd, 1999) that take the catch matrix as exact, the latter are still used for flatfish stocks in Europe. Problems may also arise from non-stationarity of data (Mohn, 1999), or from an incorrect model specification, for instance because substantial components of the stock migrate between different areas

(Kell et al., 2004a), because the assumption of constant natural mortality is violated, or because biological realism is lacking (Kell and Bromley, 2004b).

The calibration of any assessment model requires a reliable and unbiased indicator of temporal population trends. The use of commercial catch rates is problematic in this respect owing to potential changes in spatial distribution of the resource (Paloheimo and Dickie, 1964), in the spatial distribution of the fleet relative to the resource (Walters, 2003), in the technical efficiency of the fleet (Marchal *et al*., 2001, 2003; Rijnsdorp et al., 2006), in interactions among vessels (Gillis and Peterman, 1998), as well as to effects of management measures on catchability (Marchal *et al* 2002). Research vessel surveys have the advantage that sampling can be standardized, but the number of tows will inevitably be small compared to the use of commercial fleet data, leading to wide confidence limits. And also for research vessel gears the assumption of constant catch efficiency may not hold because it may be affected by changing fishing patterns of the commercial fleet through disturbance of fish or interactions among vessels (Gillis et al., 1998; Rijnsdorp et al, 2000ab; Gillis, 2003). On a longer time scale, fisheries-induced evolutionary changes in the behaviour of fish towards fishing gear may reduce catch efficiency (Heino and Godø, 2002).

Retrospective errors in stock assessment are important in the context of the credibility of management advice and their effects should be clearly communicated to the customers. Assessment results are commonly presented as the singular, best possible representation of the current status of a stock (Corkett 2002; Finlayson 1994), while errors in the past are ignored as being non-informative. However, even if those errors can be clearly explained, we argue that the uncertainty should be presented as integral part of the assessment to convey its limitations (Pastoors, 2005).

There is generally one year between the last population estimate of the assessment and the forecast year for which TAC advice is requested. Uncertainty about the total catch in the ongoing year may have far reaching consequences for the TAC advice. If management aims for status quo F, the random error in the estimate of stock size will be largely balanced by an opposite error in the estimate of F. However, if management aims for a reduction in F - as is often the case given the depleted state of many stocks - or if there are systematic trends in biological parameters such as growth and maturity or in the spatial dynamics of the fishery, the uncertainty and bias will propagate in the short-term forecast (Cook et al., 1991; Gascuel et al. 1998; Van Beek and Pastoors 1999; Pastoors, 2005). This may result in a TAC advice that is either too restrictive or too loose for several years to come. If stocks are already in danger, a systematic bias of this sort may be particularly dangerous and increase the risk of stock collapse.

Management of mixed fisheries

The failure of mixed fisheries management under the CFP may be illustrated by the historic trends in spawning stock biomass (SSB) and fishing mortality rate (F) of three major demersal stocks in the North Sea (Figure 3). The SSB of cod has declined to a level below the limit reference point for sustainable exploitation, whereas the SSB of plaice and sole declined to a level just above the limit. In sole a temporary increase in SSB can be observed following the recruitment of two extremely abundant year classes in 1987 and 1991. The F in cod remained above the limit reference level, whereas the F in plaice has been below the limit reference level throughout the time series. For sole, no limit reference level is determined.

Figure 2 also provides information on the TAC advice in terms of F given by ICES and on the F corresponding to the TACs agreed by the Council of Ministers, which may be compared to the realised F subsequently. At the start of the CFP, the F that corresponded to the recommended TAC (F_{rec}) was only slightly below the actual F for cod. In 1986, F_{rec} was reduced to a level of ~0.6 until 2001 when the advice was no fishing (F_{rec} =0). With a time lag of two years, the Council of Ministers closely followed the scientific advice and agreed on a TAC that was only slightly above the recommended value, corresponding to a $F_{TAC.}$ only just above F_{rec}. Since 2001 when the advice was zero catch, a TAC of about 50.000 t has been agreed, corresponding to a F_{TAC} =~0.5. Although this F_{TAC} was well below the current level since 1988, it did not achieve the intended reduction in F (Figure 3a). In plaice, the scientific advice based on F_{MAX} (until 1985) was relaxed first to reduce F (1986-1989) and subsequently to status quo (1990-1994). Since 1995, when SSB showed clear signs of declining, a strong reduction in the TAC was recommended to rebuild SSB above the minimum level required for sustainable use. The agreed TAC and corresponding F_{TAC} , however, was generally well above the recommended F, and between 1985-1994 even above the realised F (Figure 3c). Since 1995, the agreed TACs have become restrictive and realised F appears to have decreased slightly although it is still well above the agreed F_{TAC}. In sole, a similar relaxation of the scientific advice can be seen between the mid 1980s (reduction in F) and the period 1993-1996 (status quo F). Since then, a reduction in F has been recommended corresponding to the precautionary reference point for forecast (F=0.4). Despite the nominally restrictive TACs set since 1995, there is no clear evidence for a reduction in realised F, except perhaps in the last year (Figure 3e). As part of the recovery plan for cod, the restrictive TACs in the mixed fisheries have been accompanied by additional measures such as a closed area in 2001, and since 2003, a restriction of the number of fishing days to 10-23 days per month depending on fishing gear.

The relaxation in the F advice in the late 1980s and early 1990s was related to a shift in philosophy that changed the 'scientific' objective from F_{MAX} to keeping the stock above a minimum biologically acceptable level (MBAL). In practice, this meant that medium term considerations were ignored and a warning was issued only if spawning stock biomass would fall below MBAL in the TAC year. In the mid 1990s, the precautionary approach was implemented and the medium-term perspective led to a substantial reduction in F_{rec}.

The deviance between realised F and F_{TAC} (Figure 3) can be partly explained by a bias in stock assessment, which has caused underestimation of F in recent years (Figure 2). Between 1995 and 1999, the average difference in apparent F between the original assessment and the converged assessment later has amounted to 50%, 32% and 18% for cod, plaice and sole, respectively, whereas the average difference between realised F and the agreed F_{TAC} during this period was 76%, 36% and 28%, respectively. For cod, there is a suspicion that the actual catch has exceeded the official catch because of misreporting in those years (ICES, 2005a). For plaice and sole, anecdotal information from the fishing industry suggests that in certain periods a part of the catch may have been subject to high-grading.

The main conclusion here must be that the CFP has not achieved the envisaged reduction in F in the three demersal stocks even though agreed TACs formally should at least in most years have been restrictive. The cause of this failure, however, is less clear. The origin of the apparent bias in stock assessment is uncertain, but may be related to the assumption of constant catchability. Another, potentially related cause is the potential discrepancy between actual and reported landings. Whatever the cause, the lack of a medium term perspective in the formulation of the scientific advice during the late 1980s and early 1990s allowed the fisheries to continue on a level that is now considered to be unsustainable in the long term. A final observation is that the Council of Ministers frequently agreed on a TAC well above the recommended catch option. The failure of fisheries management for mixed demersal stocks is not only restricted to the examples shown here but also applies to many other demersal stocks in European waters (ICES, 2005b).

Their management history contrasts markedly with the herring stocks, which are mainly taken in directed, single-species fisheries. In the 1960s, the North Sea herring stock was severely depleted (Simmonds, 2005). After a four-year moratorium between 1978 and 1982, the stock showed signs of recovery and the fishery was allowed to take a modest TAC, which was gradually increased during subsequent years. In 1996, ICES advised to halve the already agreed TAC for the ongoing year, because a new collapse threatened. The European Commission acted accordingly, which resulted in a reduction in realised F from 0.75 to 0.4. Although the realised F was still well above the agreed F_{TAC} and problems in misreporting remain, in this case the TAC management system appears to have been successful in regulating fishing mortality rate to levels that allowed the stock to rebuild to the management targets (ICES, 2005b; Simmonds, 2005).

The failure of the TAC management in mixed demersal stocks, may have been exacerbated by the apparent decline in the productivity of demersal species after the gadoid outburst in the 1960s (Pope and Macer, 1996; Hislop, 1996): recruitment of various roundfish species (Hislop, 1996) and plaice (Kell and Bromley, 2004) declined and also growth rates of plaice and sole slowed down (Rijnsdorp et al., 2004; van Keeken et al., 2006).

The credibility crisis in mixed fisheries management

Although there are many sources of uncertainty in the assessments and catch forecasts, the prime problem is the catch statistics, because the total catch serves as a direct raising factor for the estimated stock sizes. A bias in the catch data will not show up in the retrospective analyses, but will remain present in all future assessments and thus bias our perception of the historic performance as well as any reference points derived from these.

Under a TAC regime, fishers have an incentive to land over-quota fish illegally and the more restrictive the TAC, the larger the incentive. Because removals are underestimated, present stock sizes and forecasts are also underestimated. Thus, the TAC management system by its very nature has a feed-back component, which results in deteriorating catch statistics and ever more unreliable assessments. Although the warning of deteriorating catch statistics has been stated clearly in almost every ACFM report, the fact that the TAC system itself is ultimately responsible for this deterioration does not seem to have come through. Can this problem be resolved by better enforcement? The answer for mixed fisheries must be no, because it is perfectly legal to high-grade and discard over-quota catches. The effect of illegal landings and legal discards is exactly the same. Moreover, a management system that is aimed at controlling exploitation rates, but only affects the proportion landed will not result in sustainable fisheries!

Formally ICES does not provide TAC advice, even if it is requested to do so. The ACFM advice is formulated in such a way that the forecast options are selected on the basis of a suitable F-range: "ICES recommends that fishing mortality be less than F_{pa}=X, corresponding to landings of less than Y in year Z". If catch predictions are translated into TACs, the inherent assumption is that landings statistics are correct and that discarding rates are stable, while both are not.

After 25 years of experience with the CFP, one might rightly wonder, while we are still left with a TAC system that obviously does not work in mixed fisheries. Can there be any expectation that from now on everything will work as it should, without a drastic reform? Does it help the credibility of the scientific advice, if scientists keep the VPA-machine going to get all the forecasts out in time for the EU to decide on TACs that can never be properly controlled?

Solving the credibility crisis

The ultimate condition for regaining credibility would be if managers, guided by advice, would succeed in rebuilding the now depleted stocks to a sustainable level as well as preventing other stocks to reach depleted conditions. For the mixed fisheries, the current system suffers from the intrinsic imperfection that fishing may continue after the TAC of one of the target species has been taken, unless discarding would be forbidden and independent observers would control all fishing operations. Hence, a major change in the management system seems needed. Transforming the present output control system to an input control system might solve several of the existing problems (Daan 1997; Shepherd, 2003). Enforcement of restrictions of number of days fishing would seem a lot easier than controlling landings. Most importantly, however, is that the scientific assessment of the stock is not directly affected by whether fishers fool the inspection services, high grade or increase their catch rates. The basis for evaluating the status of the stock should remain correct, and adaptive rather than prescriptive management should solve any problems encountered.

Of course, a major change in the CFP will be difficult to achieve, as the institutional framework is anchored in national and international law and has evolved in a slow and complicated process (Scheffer et al., 2005). However, since the second review in 2002, the CFP includes the possibility of direct effort management on an annual basis as part of the recovery plans for depleted species (EC, 2002). Even if it is not now an alternative for TACs, this modification represents a crucial step forward by providing a legal basis for effort management. The question remains how the present TAC system might be turned into a Total

Allowable Effort (TAE) system, without compromising the starting point of ‘relative stability’, and how the management and advisory system might again gain credibility.

Converting a TAC into a TAE system

To convert a TAC system into a TAE system, an indicator of effective effort (Shepherd, 2003) by fleet (f) is required, which may be estimated from the relationship between fishing effort (E_f) and the fishing mortality realised by that fleet (F_f): $F_f = q E_f$ (Rijnsdorp et al., 2006). The TAC system assumes that national catches contribute proportionally to total F. Therefore, we may split the F_{TAC} in shares in terms of allowed partial F by fleet according to the existing percent quota shares ($F_{TAC,f}$). The catchability coefficient *q* gives the fishing mortality imposed per fishing day. With this *q* and the fishing mortality rate corresponding to the share of the agreed TAC ($F_{TAC,f}$), the total allowable number of fishing days (TAD_f) can be calculated as $TAD_f = F_{TAC,f}\, q^{-1}$. For a single vessel, the individual effort quotum will be IEQ = TAD_f / n, where n is the number of vessels in the fleet. In a mixed fisheries system, where several fishing fleets are targeting a mixture of fish species using a variety of fishing gears, the IEQ’s will be species and fleet specific.

There may be many factors causing the realised partial F of a particular fleet in the TAF-year to be different from the share allowed. Technological advances as well as human behaviour or unforeseen changes in the behaviour of the species may create discrepancies. The essence of an input control system would seem to adapt the effort according to significant, observed trends in realised F. Thus, fleets may exceed their partial F-share in any particular year, but their effort should be adjusted in an adaptive manner in the following years.

Given enough data, an effort management system might become really sophisticated. We describe one example based on real data. Because of seasonal migrations and recruitment to exploitable stock, the availability of fish will vary between areas and seasons. A fishing day, therefore, will generate a higher fishing mortality when a species is temporarily concentrated in for instance a spawning area than when the species is dispersed over the feeding grounds. An effort management system may take account of predictable variations in *q* by charging a certain price for each combination of fishing area and season. The total allowable number fishing days (IEQ) can be viewed as a currency that can be translated in actual fishing days given a conversion rate (q_{ij}) that varies in space (i) and time (*j*).

The calculation is illustrated for the Dutch beam trawl fleet targeting sole and plaice using the estimates of the partial fishing mortality generated per fishing day by each vessel during each trip (*Fpue*) as a function of engine power, fishing area and time of the year (Rijnsdorp et al., 2006). With the *Fpue* estimates for a standard 2000 hp beam trawler and the Dutch share of the TAC for sole and plaice, the IEQ can be calculated as 200 days for sole and 139 for plaice (Table 1). Because the availability of fish varies between areas and seasons (Figure 3), the conversion rate of IEQ units into actual fishing days will vary accordingly (Table 2).

Discussion

Within a TAE system, each vessel could be free to make her own fish plan within the constraints set by the available IEQ units and the conversion rates for the different species, and can land all fish above the minimum landing size. In case the national quotum is allocated into individual transferable quota (ITQ), such as in the Dutch beam trawl fleet, the IEQ would vary between vessels in proportion to their ITQs. The crucial ingredients of such a TAE system are the species and fleet specific estimates of q and the seasonal and spatial patterns in q. As the catchability generally increases in response to technological innovations (Marchal et al., 2001; Ulrich et al., 2002; Marchal et al., 2003; Rijnsdorp et al., 2006), the q's may need to be updated at regular intervals, depending on the rate of increase. Alternatively, catchabilities can already be increased by a certain percentage annually to take account of the expected increase in technical efficiency.

Some major advantages of the TAE system proposed are: 1) it offers a solution to a major deficiency of the current TAC system as there will be no incentive for misreporting or high-grading catches, which undermines stock assessment as the objective basis of the management system; 2) it allows a conversion of the current TAC system within the constraints of maintaining relative stability by using national percentage quota shares to distribute partial F shares; 3) it controls the target F's of each of the species taken in the mixed fisheries; and 4) it allows remedial action at the national level, whereas under the TAC system all countries suffer equally from reduced TACs, if one particular country has exceeded its share in sustainable exploitation by illegal landings or high grading.

A TAE system like this, however, may have deficiencies of itself that need careful consideration. The effectiveness of the approach will depend a.o. on the predictability of the seasonal pattern in q, the possibilities for vessels to increase their efficiency within the constraints set by the TAE management. One might argue that non-compliance of effort regulations may jeopardize the quality of the stock assessment as a basis for fisheries management, analogous to misreporting catches under a TAC system, because fishermen may try to under-report fishing effort to increase fishing time and generate a higher revenue. However, because there is no incentive to misreport catches, F and stock size should still be correctly estimated. Under-reporting of effort would lead to an apparent increase in catchability, and hence in a reduction in the effort quotum of that fleet after a reappraisal of the catchability, but does not influence the assessment of the stock status.

Enforcement of effort regulations will be a pre-requisite for an effective TAE system as an individual fisher may trade-off the immediate benefit of misreporting effort to the risk of getting penalized. Enforcement of effort regulations should be easier than of catch regulations, as fishers activities are already monitored by the vessel monitoring system in use within the CFP. However, effort management will need additional regulations on type and numbers of gear used (size of the trawl, number of long lines, gill nets, pots or traps), which is more difficult to control. This will need particular attention as gear use has a large influence on the catch efficiency.

In an input control system, skippers will have a strong incentive to increase their fishing efficiency. Therefore, we may expect that the transition of a TAC to a TAE system may lead to a stronger increase in catchability then observed in the past. Under the current TAC regime, catchability of sole and plaice in the beam trawl fishery has been reduced because vessels have partly redirected their fishing effort to other species for which the TAC is less restrictive (Poos et al., 2001)., Therefore, we might expect a sudden increase in catchability of the most valuable species in particular. Such increases may only be estimated in retrospect and TAE management is unlikely to control fishing mortality precisely at the agreed level (F_{TAC}).

A question that needs careful consideration is the optimal spatial and temporal scale for catchability estimates as conversion units for effort quota. This should be a compromise between the utilitarian wish to have a rather simple approach and the biological reality of marked variations in space and time. If the resolution chosen is large, there will remain a structure in q present that vessels can utilise to increase their catchability above the historic average. On the other hand, smaller scale patterns will be increasingly more difficult to quantify reliably.

A TAE system is likely to stimulate investment in technological innovations, and therefore enhance competition, but this would not be a new development. Also under the TAC system vessels are out competed if their efficiency falls behind that of others. The ITQ system introduced in the Netherlands resulted in a concentration of fishing rights (Davidse, 2001), and even within the European Union, re-flagging of vessels has led to a concentration of fishing rights that is incompatible with the concept of relative stability (Hatcher et al., 2002). If in the Netherlands, the allocation of fishing days would be directly coupled to the existing ITQ's, the monetary investments in the latter might be smoothly transferred to a TAE system.

The sensitivity of the TAE system for various sources of uncertainties may be explored quantitatively using an evaluation framework developed to explore the contribution of the various sources of uncertainty in the scientific basis for fisheries management (see review in Harwood and Stokes, 2003). This framework comprises a biological model that captures the relevant processes determining the dynamics of the resource and the dynamics of the fishery (Butterworth and Punt, 1999), an observational model that analyses the sampling data obtained from the biological model, leading to a perception of the state of the stock and a management model that determines the management actions based on strict harvest control rules. In all model components, the relevant factors contributing to uncertainty and error are taking into account. By comparing the perceived with the true dynamics, the sensitivity of the management system for various sources of error and uncertainty in any of the three models may be explored. This approach is a major step towards improving fisheries management advice and has been explored for North Sea flatfish and roundfish by Kell et al. (2004, 2005) and Kell and Bromley (2004). The TAE system proposed should be a suitable candidate for testing.

A TAE approach may also contribute directly to the protection of North Sea cod. Since 2001, ICES has advised to stop fishing for cod in order to rebuild the stock. However, as this species is taken as a bycatch in a large number of demersal fisheries, it has proven politically unacceptable to stop all cod-related fisheries. Applying our approach, the matrix of *q* values by area and season of all cod related fisheries may be estimated for cod as well as the other demersal species managed by single species TAC's taken in the cod-related fisheries. This matrix should allow managers to find a compromise in minimising the total F on cod, while maximising the allowable F on the other species within the agreed F_{TAC}, taking account of the share of the various countries (relative stability).

The input control system proposed here should not be considered a panacea for the solution of all problems in mixed fisheries management. Although it addresses the key problem - the control instrument (TAC) undermines the scientific basis of management (stock assessment) – that needs to be resolved with high priority, other problems may prevent fisheries management to become successful. Other problems, for instance the improvement of the stock assessment models with regard to uncertainty and bias (Figure 1) (Mohn, 1999; Harwood and Stokes, 2003), but also problems related with the complexity and non-equilibrium nature of marine systems (Caddy and Seij, 2005), fisheries dynamics and their response to the management regulations (Gillis et al., 1995; Gillis, 2003; Dinmore et al., 2003; Salas and Gaertner, 2004), enforcement (Payne and Bannister, 2003), lack of transparency of the management system and the governance structure (Gray and Hatchard, 2003; Dawn and Gray, 2005) need to be resolved. The proposed alternative converts an already complicated TAC management system into an equally complicated TAE system that depends heavily on fisheries dependent data. Alternative solutions might be found in a more simple management system that is less dependent on precise stock assessments but manage exploitation rate based on a number of transparent and simple indicators of the trends in resource biomass and fishing effort (Degnbol, 2005). However, it seems unlikely that man will ever be able to manage fish stocks without managing the amount of fishing by individual fleets. In order to achieve the sustainable management of mixed fisheries we need 1) a carefully designed management system that takes account of the dynamics of the resource and the dynamics of the fisheries; 2) a governance system that acknowledge the separate roles of the scientist, managers and fishermen and accepts the impartiality of scientist and 3) an efficient and transparent enforcement system. The impartiality and quality of the fisheries science could be enhanced if the evaluation of the management system and exploration of alternative systems would be part of the routine research agenda.

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Table 1. Hypothetical calculation of the Total Allowable Effort for the Dutch beam trawl fleet fishing for sole and plaice based on the partial fishing mortality rate generated per fishing day by a typical 2000 hp trawler.

	Sole	Plaice
Agreed F	0,4	0,25
NL share of F	0,3	0,125
q	1,0E-05	6,0E-06
TAD (days at sea)	3,0E+04	2,1E+04
#vessels	150	150
IEQ (#days/vessel)	200	139

Table 2. Seasonal differences in the price that a fishing vessel has to pay for fishing for one day in four different fishing areas in the North Sea. If a vessel decides to fish in August in area South for 10 days, its IEQ will be reduced by the 5 units for plaice and 13 units for sole.

	Plaice				Sole			
month	South	West	East	Central	South	West	East	Central
1	1,7	1,2	1,6	1,0	1,1	1,0	0,7	0,0
2	1,3	1,0	1,5	1,2	1,1	0,9	0,7	0,0
3	0,6	0,8	1,0	1,5	1,2	0,9	0,8	0,0
4	0,5	0,8	0,7	1,4	1,1	0,7	0,8	0,0
5	0,6	1,1	0,7	1,3	0,9	0,6	0,8	0,0
6	0,6	1,0	0,8	1,3	0,9	0,7	0,7	0,0
7	0,4	0,9	0,6	1,4	1,1	0,7	0,9	0,0
8	0,5	0,9	0,6	1,3	1,3	0,7	1,2	0,0
9	0,7	1,0	0,7	1,3	1,5	0,8	1,5	0,0
10	0,9	0,9	1,1	1,3	1,5	0,9	1,3	0,0
11	1,0	0,9	1,2	1,2	1,5	1,1	1,0	0,0
12	1,3	1,1	1,3	1,0	1,3	1,1	0,9	0,0

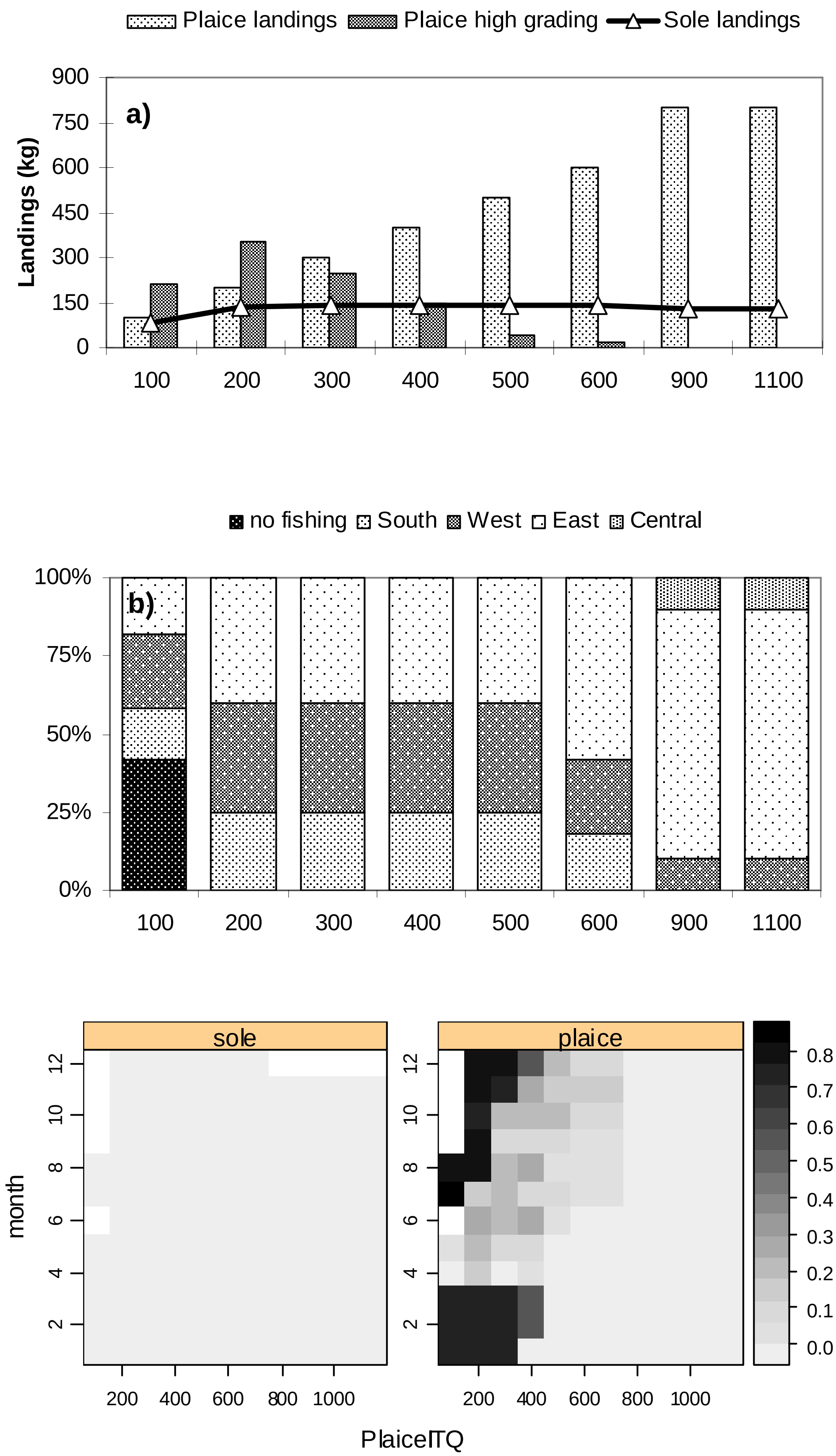
Legends of Figures

Figure 1. Sole and plaice landings (a), effort allocation over 4 fishing grounds with various abundance of sole and plaice (b) and the proportion of the catch that is high graded by month (c) of the Dutch beam trawl fleet fishing under various levels of ITQ for plaice. The abundance of sole and plaice varied seasonally over the 4 fishing grounds as shown in Figure 4. At the highest level the ITQ for plaice is not restrictive and the fleet mainly fishes in the east where both sole and plaice are abundant. At lower plaice ITQ, the fleet targets areas where plaice is less abundant (south and west) and increasingly discard the plaice catch that exceeds the ITQ. At the lowest ITQ, vessels stay in harbour for 40% of the time (Poos et al. 2006).

Figure 2. Difference in the estimated mean fishing mortality (F) in the year of the year of the assessment (□) and the most recent assessment (♦) for North Sea cod (a), plaice (b) and sole (c).

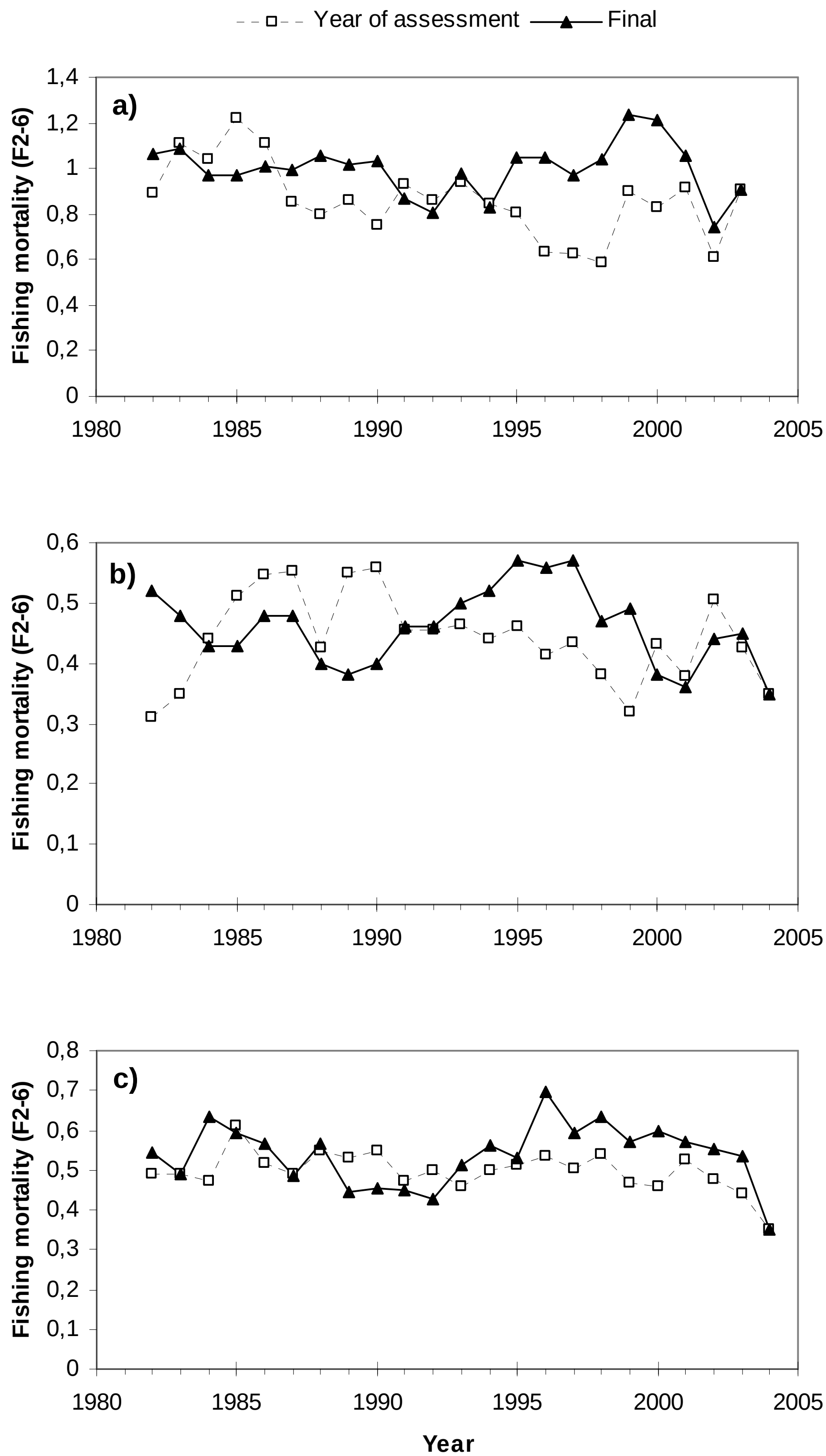
Figure 3. Summary of the trends in fishing mortality F (left) and spawning stock biomass SSB (right) of cod (top), plaice (middle) and sole (bottom). Fishing mortality (F) estimated in the most recent stock assessment (drawn line) is compared to the fishing mortality F_{rec} (□) corresponding to the recommended TAC and F_{TAC} (■) corresponding to the TAC that was agreed among the Council of Ministers. The horizontal black lines indicate the limit reference levels for F and SSB, the horizontal grey lines indicate the precautionary level of F.

Figure 4. Seasonal changes in the conversion rate of a unit of fishing effort in four different fishing areas in the North Sea (South, West, East and Central) for plaice (a) and sole (b). The conversion rate curves reflect the differences in the availability of the resource between fishing areas and month.



Plaice landings
Plaice high grading
Sole landings
Landings (kg)
a)
900
750
600
450
300
150
0
100
200
300
400
500
600
900
1100
no fishing
South
West
East
Central
b)
100%
75%
50%
25%
0%
100
200
300
400
500
600
900
1100
sole
plaice
month
2
4
6
8
10
12
200
400
600
800
1000
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PlaiceITQ

Figure 1. Sole and plaice landings (a), effort allocation over 4 fishing grounds with various abundance of sole and plaice (b) and the proportion of the catch that is high graded by month (c) of the Dutch beam trawl fleet fishing under various levels of ITQ for plaice. The abundance of sole and plaice varied seasonally over the 4 fishing grounds as shown in Figure 4. At the highest level the ITQ for plaice is not restrictive and the fleet mainly fishes in the east where both sole and plaice are abundant. At lower plaice ITQ, the fleet targets areas where plaice is less abundant (south and west) and increasingly discard the plaice catch that exceeds the ITQ. At the lowest ITQ, vessels stay in harbour for 40% of the time (Poos et al. 2006).



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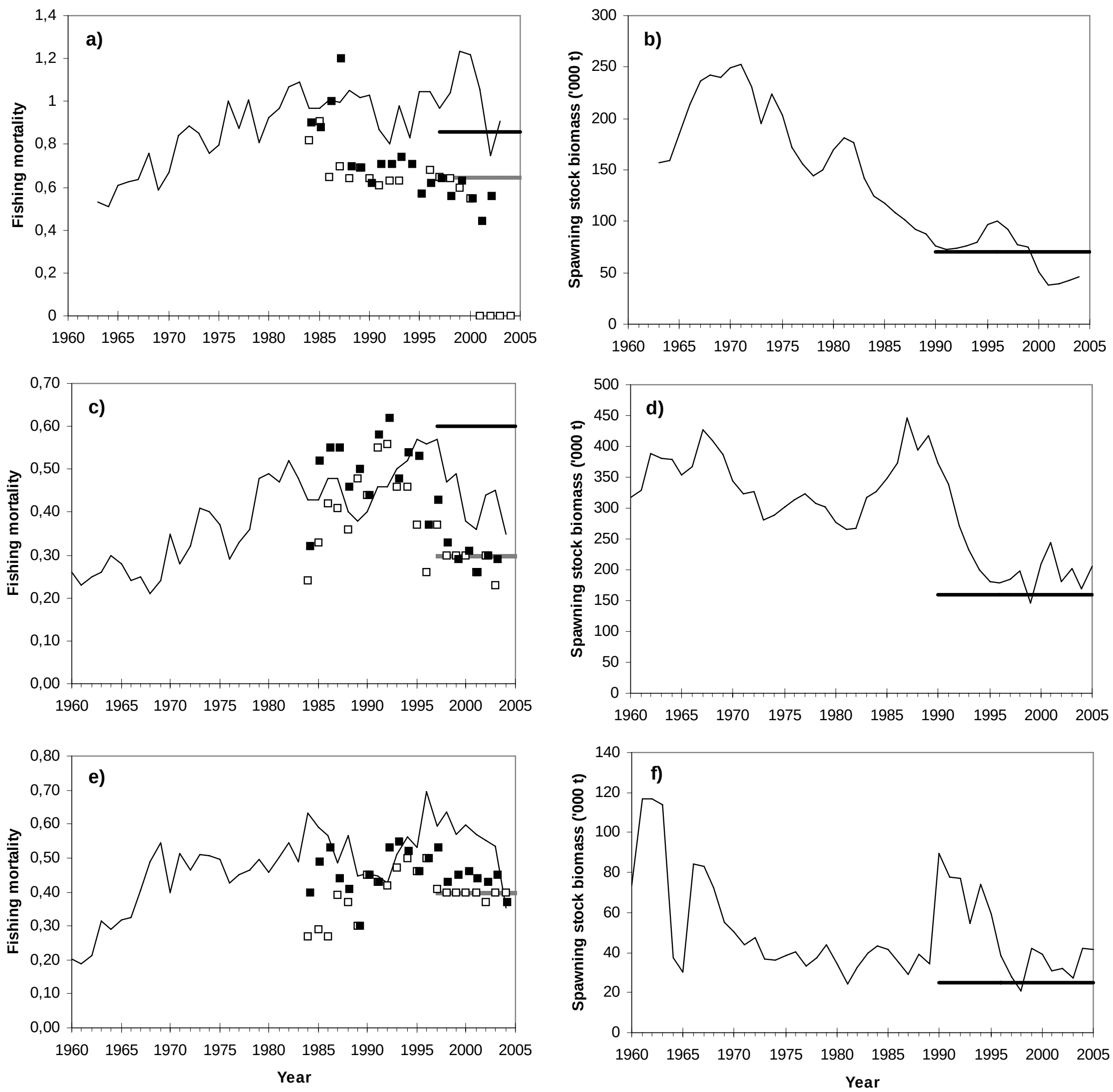

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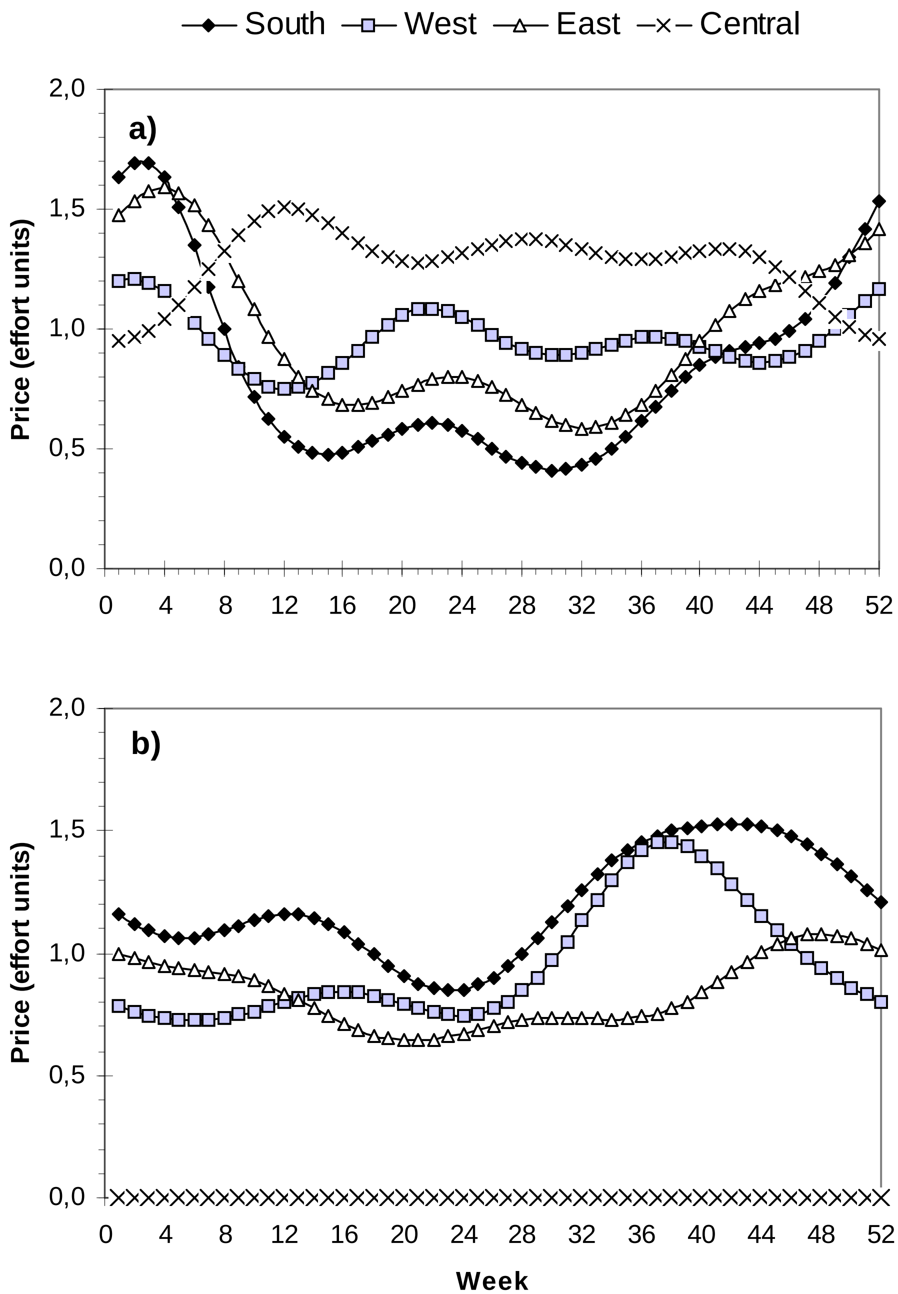

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