Slipping through our hands. Population of the European Eel

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A conceptual management framework for the restoration of the declining European eel stock

The stock of the European eel (*Anguilla anguilla*) is in a critical state. A prolonged downward trend in landings since 1960 suggests a steady decline of the continental stock, while incoming recruitment fell to record low levels in the 1980s over almost all of Europe. Although the effect of oceanic factors cannot be ruled out, continental processes depleting the spawning stock are the more likely cause. An innovative management scheme preserving adequate spawner production is urgently required. Setting objectives and post-evaluating effects typically constitute the roles for the global level; implementation via specific management measures and monitoring of the stock must be performed locally, coordinated over all management levels. Eels are long-lived animals, and research and management are slow processes. Analysis of the population dynamics indicates the stock has been in slow transition in the past two decades, from a stable and high abundance towards a secondary stable state, near extinction. It has taken considerable time to recognise the decline; it will take further time to develop and implement an appropriate management framework. The longer we wait, the lower the odds for reversing the downward trends. One must act. Now!

The stock of the European eel (*Anguilla anguilla* (L.)) has shown a marked decline over the last decades. Recruitment to (Moriarty 1986; Dekker 2000a) and yield from (Dekker 2003d) the continental stock have been well below average for two or more decades. Several authors have speculated on possible causes of the decline (Castonguay et al. 1994a; Moriarty and Dekker 1997; ICES 2002a), but none of the hypotheses so far explains the observed decline adequately (Dekker 2003b). A stock protection and recovery plan is urgently needed (ICES 1999), but no substantial progress in managing the stock has been accomplished (ICES 2004) while the decline continued (ibid.). Scientific advice to restrict fisheries to prevailing levels (ICES 1997a), to re-distribute recruitment of glass eel towards the outskirts of the distribution area (Moriarty and Dekker 1997), or to reduce all human impacts on the stock to as close to zero as possible for some time to come (ICES 2002b), has not yet been followed, despite the intention to secure sustainable development of eel fisheries.

In the past decades, substantial effort has been invested in the formulation of a precautionary approach to exploitation of fish resources (United Nations 1983; FAO 1995) and the derivation of quantitative reference points for fisheries management (Caddy and Mahon 1995; ICES 1997b). This framework is now routinely applied for scientific advice on the exploitation of typical (marine) fish stocks in Europe (ICES 1997b), and has been the basis for the advice on eel (ICES 1999, 2002b). However, despite the alarming state of the eel stock, few actual management measures have been taken (ICES 2004).

In this paper, existing evidence on the decline of the stock will be summarised, potential causes reviewed, and a conceptual framework for management of the stock presented. In this article, I will use the word *eel* (without qualification) to indicate the European eel, although the presented ideas will probably apply to management of other (temperate) eel species too.

Managing the stock: an impossible bargain?

Management strategies readily applied to many other fish stocks might not work as well for eel (Feunteun 2002). Complications arise from the eel’s biology, fisheries and management.

The eel stock in Europe, northern Africa and Mediterranean Asia (Dekker 2003a) constitutes an (almost) panmictic population (Wirth and Bernatchez 2001; Avise 2003). Reproduction has not been observed in the wild, but all evidence supports the view of a semelparous reproduction, in or near the Sargasso Sea, at 3000-7000 km from the continent. The fisheries, in contrast, are scattered all over
the continental distribution area, in an estimated number of >10,000 waters (Dekker 2000a). Managing the stock engages fisheries, scattered over more than 30 countries, of which 10 are regularly involved in international research and management (unpublished data from the author). The commercial fisheries are rarely and only weakly organised, whereas national or regional authorities generally have minimised their involvement. Legislation of fisheries often considers typical marine and fresh water environments, with the possible addition of a separate heading for salmonids, none of which fits the peculiarities of the eel.

The continental life stage lasts for 5 to 15 years. During this phase, the stock is exploited in the migratory life stages (gla$eel and silver eel), and the resident life stage (yellow eel). Concentrated in space during migration, or vulnerable to exploitation over many years, the eel is a preferred target for exploitation, yielding more than double the price (FAO 2000) of other fish (except sturgeons, at double the price of eel). The long migration routes require accessible routes from the sea towards inland waters. Additionally, the occurrence in up to the smallest water systems maximises the vulnerability to anthropogenic impacts, such as pollution, habitat loss and poaching. Highest stock densities are found in lowland river stretches, around which human populations reach peak densities. Managing the eel comes down to managing anthropogenic impacts that often affect the eel only indirectly.

Typical fish stock management relies heavily upon scientific information on the status of the stock, and the impact of exploitation, as well as upon opportunities to steer the exploitation pressure. For the eel, neither the knowledge nor the management opportunities satisfy the current needs adequately, while conflicting anthropogenic interests complicate the matter. Rather than giving in to this seemingly impossible bargain, I will analyse the problem below and assemble a suggestion for a solution from existing nuts and bolts of fish stock management.

**Status of the stock**

The overall status of the eel stock is hardly known (Moriarty and Dekker 1997). Neither the absolute size, nor the overall impact of exploitation and other anthropogenic factors have been assessed with any accuracy (Dekker 2000b). Local monitoring series have been run because of local application, but posterior meta-analyses have shown common downward trends in large parts of the distribution area, in recruitment (Dekker 2000a) and fishing yield (Dekker 2003d).

**Recruitment from the ocean**

In southwestern parts of the distribution area, commercial fisheries are found in estuaries and river mouths, targeting glasseel freshly recruiting from the sea (Moriarty and Dekker 1997; Dekker 2003a,d). For a number of river systems, landing statistics of the fisheries have been record-
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Figure 2 Landings from the European eel stock during the 20th century. Statistics on eel landings have been recorded by a total of 37 countries. Some of these data series run for more than a century, while others show a few recent records only; administrative regions have changed over the years and resulted sometimes in double counting; (indoor) aquaculture production is ultimately derived from the natural stock, and is sometimes erroneously included in (outdoor) fishing yield. Consequently, the raw FAO statistics (FAO 2000) falsely suggests a non-decreasing trend, while reconstruction of the total landings indicates a continuous decline since the mid 1960s (Dekker 2003d).

Yield from continental waters

Fisheries for yellow and/or silver eel are found throughout the distribution area of the species (Dekker 2003a,c). Statistics on total landings are notoriously incomplete. ICES (1988) and Moriarty (1997) have shown that official statistics often comprise only about half the true catches. However, reported data series display a common trend in most of the 20th century (Figure 2; Dekker 2003d), showing a peak in the 1960s, corresponding to a total yield of 47,000 t, to decline slowly to a historic low of less than 15,000 t in 2000.

This trend in yield parallels a seeming trend in the stock, detected in various sources of circumstantial (Moriarty and Dekker 1997) and direct (Dekker 2003b) evidence. Thus, the trend in yield is apparently due to a change in stock abundance, rather than to variation in fishing pressure. For Lake Ijsselmeer (the Netherlands), research surveys have directly evidenced a declining trend in the stock since 1960 (Dekker 2003b).

Causes of the decline

The decline in recruitment was first noticed in 1985 (EIFAC 1985). The prolonged decline in yield has been mentioned as early as 1975 (ICES 1976), but has received
considerable less attention than that in recruitment. Several hypotheses for the decline in recruitment have been suggested (Castonguay et al. 1994a; Moriarty and Dekker 1997; ICES 2002a), but without proper evidence, no definite causes can be identified, and a parallel effect of several of the proposed causative factors is most plausible (Dekker 2003c).

The suggested hypotheses categorise into two distinct groups. On one side, one has suggested some process in the ocean might have reduced larval survival and/or growth (Castonguay et al. 1994b; Desaunay and Guerault 1997; Dekker 1998), which process might possibly be related to the North Atlantic Oscillation (ICES 2001a; Knights 2003). This process is unlikely to be anthropogenic, and will not be related to the size of the spawning stock. Recovery of the original climate conditions is expected to lead to restoration of the abundant recruitment almost immediately. The observed spatial correlation in the decline in recruitment, as well as the assumed impact on the (nearly) panmictic oceanic life stages indicate, that oceanic processes operate on the stock as a whole.

On the other side, a range of continental factors has been suggested, including pollution, habitat loss due to barrages and dams, overexploitation of either glasseel or yellow and silver eel, and man-made transfers of parasites and diseases (Castonguay et al. 1994a; Moriarty and Dekker 1997; ICES 2002a; Robinet and Feunteun 2002). All of these factors are anthropogenic, operate primarily in the continental life stages and affect the abundance of recruitment only through their effect on the size or quality of the spawning stock. When a fatal reduction in the size or quality of the spawning stock occurs, an abrupt drop in recruitment is expected. This will be hard to reverse, since lower recruitment in turn will reduce the spawning stock. Each of the processes impacts a local substock on the continent, but it is their combined effect on the shared spawning stock that will have caused the recruitment decline, ultimately.

Although tentative analyses indicate, that the latter group of hypotheses (continental factors) fits available data better (Dekker 2003d,e), no evident and ultimately convincing proof exists. A stock restoration plan must be developed in the absence of fully adequate scientific information (FAO 1995). However, excessive anthropogenic impacts on the stock must be curtailed irrespective of the ultimate cause of the decline. Whether these impacts have summed up to cause the global decline of the stock or not, hardly affects the need to take conservation measures.

**A framework for the management process**

In the past decades, a precautionary approach to exploitation of fisheries resources has been developed (United Nations 1983; FAO 1995). This framework is routinely applied for scientific advice on fisheries (ICES 1997b), including advice on the European eel stock (ICES 1999, 2002b). Caddy and Mahon (1995), in their discussion of quantitative reference points, outline the conceptual steps in the development of quantified reference points for fisheries management. The current discussion will extend their ideas, distinguishing between the management process proper (Figure 3, top row) and the development of scientific advice (bottom row) and elaborating on the special case of eel fisheries in Europe.

Recent scientific advice and the current discussion were triggered by the decline in recruitment observed since 1980. In the preceding decades, management focused on the development of stock and fisheries, as witnessed by the execution of large-scale re-stocking programmes (Dekker 2003c), but this has been replaced recently by a focus on stock protection. The coincidence of the decline in recruitment during the 1980s and 1990s with the upsurge in discussions on stock protection implies, that the current collapse of the stock goes beyond limits acceptable for management. If possible, the stock should be sustained at levels above those currently pertaining.

The biology of the eel has been described as incompletely and poorly known, providing only a weak basis for management and restoration (ICES 1976, 1999; Moriarty and Dekker 1997; Tesch 1999). In its general form, this claim embraces two aspects: qualitatively

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**Figure 3** A framework of conceptual and technical steps in the implementation of a management scheme for fisheries (after Caddy and Mahon, 1995; strongly modified). Arrows indicate the flow of concepts, information and data.
speaking, processes operating on the stock might be unidentified; on the quantitative side, parameters of the processes and the state of the stock might be inadequately known. In the 1970s and early 1980s, attention was focused on quantification, on the compilation of an international database on stocks and fisheries, but in the 1990s, focus shifted to possible causes of the observed recruitment decline. All suggested hypotheses fit in the general framework of fish population dynamics, that is: if more data had been available, a straightforward selection and elimination procedure could easily have shown which process caused the observed decline. But neither the data, nor a shared analysis exists. Twenty years after the onset of the recruitment decline, the scientific community working on eel still lacks a comprehensive technical model for the dynamics of the population. Analysis of the (potential) processes causing the current stock decline is still in a pri-mordial phase, tracing true and spurious correlations. Thus, the derivation of preliminary reference variables and values for stock management (ICES 2001b) hinges on the assumed parallel to quite unrelated fish species and does not relate to existing management practices.

Management and monitoring of eel stocks have a long tradition, related to regulation of local exploitation, but there is a marked regional variation in approaches, reflecting the widely differing traditions in eel fishing and consumption. Local monitoring activities have been shown to provide reliable information on the overall status of glasseeel recruitment (Dekker 2000a, 2002), but assessment of fisheries and escapement has not been tried. Management measures have been listed (Moriarty and Dekker 1997; ICES 2001a, b), but have not been related quantitatively to objectives or stock status. Clearly, there is an intention to protect and restore the declining stock, there is a list of tools available, but the connection between implementation of management measures and fully detailed scientific advice is still lacking completely.

Temporal and spatial scales of stock dynamics

Management, monitoring and fundamental research of eel stock and fisheries have been carried out at the national level, almost without co-ordination between the individual countries. The spatial distribution of the stock exhibits fractal characteristics, showing large-scale as well as small-scale variation (Dekker 2000b); the temporal structure shows comparable fractal patterns. In setting up a management system for the stock and fisheries, these patterns should be considered and an appropriate spatial and temporal scale for management actions must be selected. In this section, the major processes in the dynam-ics of the stock will be characterised in time and space (Figure 4), setting the scene for a corresponding management scheme, developed later.

The European eel is distributed in almost all continental waters of Europe, along the coast of northern Africa and the Mediterranean parts of Asia. That is probably the most widely distributed exploited single fish stock, but individuals in inland waters are confined to single rivers or lakes, of less than 10 km² on average (Dekker 2000a). In comparison to many other exploited fish species, the eel shows an extreme longevity, related to the slow growth and late maturation. Age at maturation for female eel ranges from 5 in the Mediterranean to 15 years in the Baltic (Vøllestad 1992). In contrast to this small-scale and long-duration character of the continental half of the life cycle, the oceanic life phases cross thousands of kilometres (Van Ginneken and Van den Thillart 2000), in a most likely time frame of approximately two years (McCleave et al. 1998). In this life phase, individuals from different continental origin contribute to a common spawning stock (Avise 2003). The ocean phase thus characterises as a short-duration and large-scale phenomenon.

Anthropogenic impacts on the stock, including fisheries, range from instantaneous (e.g. pollution incidents, glass and silver eel fisheries) to long-term effects (e.g. gradual land reclamation, yellow eel fisheries). However, most of the anthropogenic impacts affect only a minor part of the population directly. Spatially significant effects only occur where local impacts are driven by a common force, such as the worldwide demand for glasseeel, or the

![Figure 4 Temporal and spatial scale of observed trends, major processes and anthropogenic impacts on the stock.](image-url)
continent-wide industrialisation. Incidents such as pollution spills seldom cover more than an isolated area, and are hardly of influence on the stock. Significant anthropogenic impacts operate on small spatial, but prolonged temporal scale. Stock-wide effects only occur because of external synchronisation between impacts on isolated and small waters.

The glass eel decline has been described as a prolonged stock-wide recruitment failure (Dekker 2000a). But as early as in 1985 (EIFAC 1985), it was realised that the recruitment of the European eel was in decline in the major part of the distribution area, that is: within five years, a widespread regime shift was noted. The gradual decline in fishing yield, in contrast, began in the mid 1960s and has continued almost consistently, that is: it has an inherently prolonged temporal scale. Like the recruitment failure, it occurred throughout the distribution area.

There is a sharp contrast in temporal and spatial scale between the oceanic (wide-spread, short time frame) and continental life stages (localised, long-lived); anthropogenic impacts predominantly fit the patterns of the continental phase, but the widespread and gradual decline in fishing yields suggests a causatory process of a different temporal and spatial scale: wide-spread and gradually developing.

**Cracking the management problem**

The contrast in spatial and temporal scale in major processes and anthropogenic impacts, sketched above, poses serious problems for management of the stock. Long-term global objectives must be achieved by small-scale and immediate actions in rural areas all over the continent. Neither central managers without direct influence on rural fisheries all over Europe, nor national or regional managers benefit of opportunities to influence the overall stock, will be able to solve the problem, unless a dedicated framework is developed. In this section, I will propose elements of a management scheme (Figure 5) that might achieve this goal.

**Objective and target**

Implicit in the development of a precautionary approach is the assumption that there is a relationship between spawning stock and recruitment. The precautionary approach dictates that, unless proven otherwise, such a relationship between stock and recruitment should also be assumed to exist for the eel and available evidence seems to corroborate the relation (Dekker 2003d). Current scientific knowledge is inadequate to derive spawning stock size targets specific for eel. Under data poor conditions, exploitation securing 30% of the virgin spawning stock biomass is generally considered a reasonable provisional reference target. This rule is conventionally labelled as %SPR, for Percentage Spawner Production per Recruit, which presupposes spawner production is proportional to recruitment. In southwestern Europe, with overabundant recruitment (Dekker 2003a), silver eel production is more likely to be proportional to (accessible) habitat, disabling the per recruit basis. However, the notion of a targeted spawning stock size relative to pristine conditions stands as it is. Considering the many uncertainties in eel management and biology and the uniqueness of the eel stock (one single stock, spawning only once in their lifetime), a precautionary reference point for eel must be stricter than the universal reasonable target of 30%. A value of 50% has been suggested (ICES 2001b).

**Reference points and proxies**

For the eel, the concept of protection of the spawning stock is hypothetical: spawning has never been observed in the wild. The escapement of spawners from the continental stock, however, is thought to be a good indicator of the supposed spawning stock size, for which management targets can be derived (ICES 2001a). The number of case studies actually measuring silver eel escapement is...
extremely limited (Ask and Erichsen 1976; Westin 1990; Sers et al. 1993; Pedersen and Dieperink 2000) and not likely to be extended considerably because of the research effort required. Cascading one step further, an assessment of the continental stock producing silver eels on the continent (Dekker 2000c) suffers from the same high research requirements.

Less demanding approaches, focusing on the yellow eel stock, such as the average size in the catch (Francis and Jellyman 1999), though not adequate for year-to-year management, might be suitable for long-term purposes (Figure 6). In my view, there is considerable scope for development of more low-demanding approximations to escapement targets. Management schemes for local situations can be built upon easy-to-grasp local targets, if these proxy targets correspond to their ultimate counterparts theoretically, and monitoring corroborates the net effect. For the glasseel fisheries, the concepts of stock abundance, habitat availability and carrying capacity still need to be worked out (ICES 2002a), but for this case too, a simplification in proxies will be required for implementation in any practical management situation.

**Subsidiarity and orchestration**

Management of local fisheries interacts with the common (oceanic) stock only through the immigration of glasseel and the escapement of silver eel. Intervention of international management in local fisheries need only concern the inputs (glasseel) and outputs (silver eel) of national systems. Global evaluation of local management considers the (relative) impact of local actions on spawner escapement and need not concern local means and local consequences. In particular, there is no basis for a continent-wide ban on either glasseel fisheries or silver eel fisheries, as proposed by opposing stakeholders.

Taking the subsidiarity one step further, the responsibility for management of national fisheries might be shared by governments and fisheries organisations, opening up the whole suite of co-management opportunities and tools (e.g. Pinkerton 1994). In particular, this might avoid the need to monitor and manage a multitude of water bodies, if monitoring samples only a small but representative number of the multitude of waters (random or stratified, but not fixed), and results are used to manage the fishery in the whole population of waters.

While the implementation (and monitoring) can only be executed at the lowest management level, objectives, reference points and evaluation necessarily refer to the whole population, at international level. Local managers hardly have any opportunity to influence the overall status of the stock, and have no natural incentive for implementing sustainable management. International managers, in contrast, cannot reasonably influence the stock directly, but do have an option to enforce a common objective through lower management levels, and to evaluate the global effect on the basis of local and widespread monitoring. Subsidiarity and orchestration of lower management levels constitute the global managers’ tools to achieve the overall objectives.

**Adaptive management**

At the national or regional level, global objectives and targets must be translated into actual management measures, that is: required escapement levels, mortality rates or stock abundances must be matched to a corresponding fishing effort, fishing season, mesh size, closed area etc. The quantitative effect of specific measures is generally unknown, and local experiments do not extrapolate well to other water bodies, because of differences in size, morphology, physical and chemical characteristics, exploitation patterns and ecosystem characteristics between nearby waters. Assuming the net effect of a specific set of measures on the stock and fishery is adequately monitored, an adaptive management scheme might realise the
appropriate rigour of the measures. That is: monitoring results can be used to tune management measures, establishing a short-term negative feedback in the management system (Figure 10, leftward pointing arrow).

In its initial definition (Walters and Hilborn 1976), adaptive management was introduced as an active experimenting with alternative (extreme) management regimes, to gain insight into the biological processes. For management of eel stocks in scattered waters all over Europe, only a self-regulating feedback in establishing local management measures is required. Since the overall dynamics of the stock will hardly respond to local actions, local experimenting will not gain any insight in the global processes. Local adaptive management requires, apart from correct implementation and monitoring, that measures are strengthened or weakened at short order when monitoring indicates so, in moderate steps. Big steps might overshoot the target, creating oscillations or jitter, but too small steps or delayed implementation jeopardises a convincing effect. Applying a somewhat stricter rule for weakening of restrictive measures than for strengthening creates a reference zone rather than a reference point, ensuring greater stability in the feedback system, and allowing for somewhat more severe initial measures.

Tit-for-tat

A major advantage of a continuous feedback system is its ability to correct for external perturbations. Adverse conditions (e.g. immigration of cormorants) or favourable improvements (e.g. habitat restoration) automatically translate into an optimal management regime for the prevailing conditions eventually, avoiding the need to assess local conditions for each and every water body. If, in a co-management set-up, the adaptive management considers only one easy to implement and easy to control measure (e.g. season closure), while all other potential measures (e.g. fishing effort, closed areas, etc.) are left to the fishery as voluntary options to improve their business, a conceptually very simple management model results. For the adaptive management scheme, all the voluntary options constitute external perturbations, to which the feedback will respond appropriately. For example, an overexploited state might gradually shorten the open season, while a subsequent (voluntary) reduction in fishing effort results in a longer season, only after the fish stock has restored to a sustainable level. This arrangement between government and fisheries conforms to the set-up known as tit-for-tat in game theory (Axelrod and Hamilton 1981), in which voluntary co-operation has been shown to be an optimal and stable strategy for both players.

Targets and tools

The exploitation of the eel encompasses three well-separated metiers: fishery for glassee, for yellow eel and for silver eel, operated predominantly at high, medium and low stock densities (Dekker 2003a). Additionally, loss of habitat and installation of hydropower generation plants constitute common phenomena. Rather than developing and establishing a separate management scheme for each river system in all countries (ICES 1997a), a small set of reference situations might be considered, tackling the major processes and concepts in the typical settings. In my opinion, half a dozen model systems will suffice to analyse management approaches for almost all eel fisheries in Europe, while the use of such a small set of common methodologies will greatly enhance the opportunities for monitoring, assessment and evaluation at the global level.

Habitat loss

Habitat loss might have contributed to the decline of the stock significantly, but its restoration is probably not the most urgent issue in major parts of the distribution area. The gradual decline in habitat has impacted the continental population, resulting in steadily decreasing spawner escapement. In the 1980s, recruitment suddenly failed. Although loss of (accessible) habitat might ultimately have caused this collapse (through a stock-recruitment relation), cause and effect are definitely not in proportion: the declining spawning stock has switched recruitment to a much lower state. Recruitment has declined to 1-10% of former levels, which requires only 1-10% of the former habitat, until the stock-recruitment-relation switches back to its abundant state. Re-stocking and (local) trap and transport programmes have been shown to contribute to fishing yield. Where increased recruitment benefits production, available habitat cannot be the limiting factor.

In contrast to the rest of Europe, southwestern France and the Iberian Peninsula receive abundant recruitment (Dekker 2000b, 2003a), and here, the amount of (accessible) habitat is of paramount significance. Since the highest loss of habitat (Moriarty and Dekker 1997) has occurred exactly in the areas of highest recruitment (Dekker 2003a), local restoration projects in the Bay of Biscay and the Iberian Peninsula might have significance for the global stock. However, unlike management of fisheries, in which long-term gains are balanced to short-term profits for a single stakeholder, setting targets for habitat restoration requires Solomonian judgements between stakeholders, between fish conservation and, for instance, agricultural irrigation. In this case, reference points cannot be derived rationally, and agreed targets express the political willing-
ness to invest in sustainable management. A pragmatic ranking of management options on the basis of their feasibility, as ICES (2002a) proposed (i.e. full use of existing habitat; restore habitat where easily done; full use of existing recruitment; restore historical habitat; restore pristine conditions), supports the Solomonian decision process, but does in no way relate to sustainable management targets or stock status.

**Glasseel fisheries**

For glasseel fisheries, it is generally assumed that fishery exploits surplus recruitment that would have experienced intense density dependent mortality if not harvested (Moriarty and Dekker 1997; ICES 2000). Although not yet explicitly evidenced, this implies a limited carrying capacity of inland habitats. Management targets relate to the abundance of the yellow eel stock, rather than the mortality rates exerted by the fishery on the immigrating glasseel. The 30 or 50 %SPR-rule allows for some reduction of the stock below carrying capacity, but doing so will yield only slightly more. Restricting glasseel exploitation progressively until no further rise in the abundance of the yellow eel stock in the hinterland occurs determines a realistic target for an adaptive management scheme. Management of glasseel fisheries thus requires monitoring of the yellow eel stock. None of the conventional fisheries regulation tools (effort restrictions, closed areas or seasons, gear controls) establishes a constant compliance under time-varying glasseel abundance. Following a substantial decline in catches, a considerably lower fishing effort in the glasseel fishery will be required to keep the yellow eel abundance at target level.

**Yellow eel fisheries**

Yellow eel fishery in inland waters yields between 1.6 and 80 (max. 400) kg•yr⁻¹•ha⁻¹ of water surface (Dekker 2003a). Since re-stocking generally has a positive effect on yield (Wickström 2001), the wide range in stock density and yield is predominantly related to variation in stock abundance, and not to carrying capacity and production potential. Management targets related to potential production (in terms of biomass states) differ considerably from those related to actual abundance (in terms of mortality rates). Because of the very unequal distribution of recruitment amongst countries (Dekker 2003a), the choice between these two options requires political back-up. However, due to its disproportionate protection of the outskirts of the distribution area and its time-varying restrictions on fisheries under temporal recruitment fluctuation, I doubt the approach based on (potential) biomass. Additionally, applying a mortality rate approach brings the major part of eel fisheries management in line with that of most other exploited fish species. Unlike the glasseel fisheries, all conventional fisheries regulation measures apply, including effort restrictions, closed areas or seasons, gear controls including minimal mesh size, and minimal legal sizes. However, setting (proxies for) management targets in terms of the average fish length excludes the use of size restrictions.

**Silver eel fisheries and hydropower plants**

During the silver eel descent from inland waters to the sea, mortality occurs due to fisheries (directed on silver eel) and hydropower generation plants (unwanted side-effect). Control of their impact on the stock is mandatory to sustain adequate spawner escapement. In both situations, the absolute amount of silver eel affected is relatively easily determined, but the relative impact on the silver eel run is hard to assess, due to the absence of direct information on the escapees. Estimation of the total number of silver eel running, based on yellow eel production estimates or mark-recapture programmes, is generally not accurate enough to warrant adaptive management. Therefore, anthropogenic silver eel mortality is probably best treated as a fixed mortality, not involved in adaptive feedback. Management measures (closed areas, closed season or periods, effort control; for fisheries as well as for hydropower generation) will be required to establish an acceptable mortality level and to keep it fixed.

**Temporal and spatial scales of the management process**

The stock and fisheries for the European eel have shown a prolonged and wide-spread decline, for which the development of a stock-wide restoration plan has been advised, requiring 5-20 years to become effective due to the longevity of the species. In the foregoing discussion, stock-wide management objectives have been discussed, essential concepts for a management strategy proposed and targets and tools for pertinent implementation in small-scale fisheries have been proposed. The question arises, whether these together constitute a viable management scheme (Figure 7).

Management of eel stocks and fisheries have been carried out for centuries on a local (national or regional) scale, aiming at various local objectives. Following the continent-wide decline in stock and recruitment, most fishermen and managers are painfully aware of the alarming state of the stock. Although views on causes and consequences may vary substantially, the willingness to amalgamate into a population-wide management net-
work aiming at restoration of the stock has been expressed by many stakeholders.

To implement the proposed framework, further development is required of proxy targets and of global monitoring and assessment programmes. Following a prolonged period of bottom-up data collection and status and trend assessment (ICES 1988-2004), strengthening the central level and imposing objective-driven, top-down management is first priority. The development of (proxy) targets is a long-term process, requiring strict coordination to acquire spatial consistency, preceding the implementation in local management. As an alternative to provisional stringent emergency measures (closure of fishery), as proposed by ICES (2002b), one might consider initiating local management aiming at the final objective, using provisional (somewhat over-restrictive) proxy targets, that is: initiate the local short-term management process immediately, rather than installing an intermediate regime all over Europe. This would also produce a start for a stock-wide monitoring and assessment programme, based on co-ordinated (but not necessarily standardised) local data series (cf. Dekker 2002).

The objective of sustainable management is a long-term widespread aim, which must be accomplished by short-term local actions. The substitution of proximate targets allows managers to implement a local management scheme, including monitoring and adaptive feedback. Because of the adaptive feedback, it will require several years before any proxy target is set and met. Additionally, the proxy targets might turn out to be rather poor representations of the ultimate goals, which necessitates intensified monitoring and assessment initially. However, due to the longevity and widespread distribution of the eel, local management can be off-target for a considerable period, as long as many local situations sum up to a global pattern meeting the global target at a temporal scale of a lifetime. If systematic bias is avoided, considerable scattering in management achievements will not jeopardise the global management objective.

The decline in yield has lasted for four decades. Subsequently, in the early 1980s, a failure in recruitment developed over a few years, but it was only in 1993 (EIFAC 1993), that the effect upon stock and fisheries was first considered, and only in 1998 (ICES 1999), that adequate management advice was formulated, while no substantial action has been undertaken yet to restore the stock (ICES 2004). In my view (Dekker 2004), the recruitment failure was a secondary consequence of the (spawning) stock decline. In turn, reduced recruitment induces a decline of the stock, and thereby establishes a very much unwanted negative feedback in the dynamics of the stock. Restoration measures will have to compensate for the ultimate causes of the decline, and to escape from the negative feedback. The longer we wait, the smaller the remaining stock size, and the lower the odds for reversing the downward trends. Current yield is about half that of 1980, when the recruitment failure began. Reckoning the trend in spawning stock developed in parallel, any management measure with an effect less than doubling the silver eel escapement will be fully in vain. Establishing an ultimately sustainable management scheme might not do anymore for the current depleted situation. Immediate and widespread restoration measures are required. Now!

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A conceptual management framework for the restoration of the declining European eel stock

Literature


