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Implications of the precautionary approach for the management of the European eel, *Anguilla anguilla*

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Abstract The European eel, *Anguilla anguilla* (L.), has a complex life history and many aspects of the biology and population dynamics of this species remain unknown or, at best, poorly understood. Relatively little is also known about the status of the stocks and fisheries, but available data suggest that recruitment of glass eels has been falling for the last 20 years and is at historically low levels. Yellow and silver eel catches have also been falling in many parts of the species range over a similar time-scale. Re-examination of the principles applied to fisheries management over recent years has resulted in the adoption of a 'precautionary approach' to the conservation, management and exploitation of fish stocks, and in an explicit need to take account of uncertainties in management to reduce risks to stocks and their environment. Such an approach is highly relevant to the management of the European eel and requires that urgent consideration is given to harvest strategies and decision structures for the national and international management of stocks and fisheries. Provisional biological reference levels should be established to provide an equable assessment of the status of stocks in all parts of Europe and to evaluate the need for management measures in all fisheries. These will need to be reviewed as further information comes available. Monitoring and research on eel stocks should therefore be enhanced and co-ordinated to improve our understanding of the status of stocks throughout Europe and the biology of the species.

KEYWORDS: *Anguilla anguilla*, biological reference levels, management, precautionary approach.

Introduction

Serious declines in fish stocks in many parts of the world over the past two to three decades and collapses of economically important fisheries have driven many fisheries organizations to re-examine the principles that they apply to fisheries management (FAO 1995a; Richards & Maguire 1998). A number of international agreements (e.g. FAO 1995b; United Nations 1995) have therefore called upon States to adopt a 'precautionary approach' to the conservation, management and exploitation of fish stocks. The underlying philosophy of this approach is that managers should 'exercise prudent foresight to avoid unacceptable or undesirable situations, taking into account that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to change in the environment and human values' (FAO 1996). Managers should therefore take account explicitly of uncertainties in making management decisions to reduce risks to the environment and specific natural resources.

The concept of precautionary action was first characterized in relation to the management of environmental issues. The 1992 Australian Inter-Governmental Agreement on the Environment, for example, defined the 'Precautionary Principle' as '*Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental damage*' (Dovers & Handmer 1995). A similar statement was used in Principle 15 of the Rio Declaration on Environment and Development to describe the 'Precautionary Approach', except that the words '*cost effective*' were added before the word '*measures*' thereby introducing economic considerations into the definition. Garcia (1996) concluded that the precautionary approach is more appropriate for use in fisheries because failure to meet management objectives (e.g. failing to maintain stocks above

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minimum biologically acceptable levels) is unlikely to threaten humanity. In addition, in most cases, although not all, the impacts of such failures are likely to be reversible, although they may result in serious damage to the resource and have significant social and economic implications.

The general principles of the precautionary approach are elaborated in the FAO Technical Guidelines for Responsible Fisheries (FAO 1996) and the United Nations Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (United Nations 1995). These international instruments have greatly influenced the thinking of other fisheries organizations that have adopted a precautionary approach, including the International Council for the Exploration of the Sea (ICES 1997a), the Northwest Atlantic Fisheries Organization (NAFO 1997) and the North Atlantic Salmon Conservation Organization (NASCO 1998). In this paper, the principles of the precautionary approach are considered, and how these might affect the management of the European eel, *Anguilla anguilla* (L.), examined. As a background to this discussion, the paper starts with a brief review of eel biology and the status of stocks, which highlights the uncertainties surrounding our current knowledge about this species.

Biology and status of European eels

Eel biology

The European eel has a complex life history and many aspects of the biology of this species remain unknown or, at best, poorly understood. The species is conventionally regarded as being catadromous, moving between fresh water (where the species grows and starts to mature) and the marine environment (where spawning occurs). It is believed to spawn in the Sargasso Sea, an area also thought to be used for spawning by the American eel, *A. rostrata* (L.), although spawning has never been directly observed for either species. Larvae (leptocephali) hatch and, for the European eel, drift with the Gulf Stream and North Atlantic currents and become widely distributed around the shores of Europe and North Africa. Leptocephali then metamorphose into glass eels, which move across the continental shelf and into near shore, coastal waters and estuaries. During this inshore migration the glass eels lay down pigment and become elvers. The conventional view has been that elvers move into freshwater systems where they grow as yellow eels. However, it has long been known that yellow eels can be caught in estuarine and coastal habitats and recent evidence from otolith microchemical analysis indicates that some eels remain in salt water throughout their life-cycle (Tsukamoto, Nakai & Tesch 1998). This suggests that the freshwater growth stage may not be an obligate migratory pathway, but the proportion of eels adopting this entirely marine life-history strategy, and the contribution they might make to the spawning stock, are not known. Eels may grow for up to 25 years in fresh or coastal waters before transforming to the 'silver' stage, although, on average, male eels migrate at an age of 7 or 8 and females at about 11 (Tesch 1977). At this stage the gonads begin to mature and the fish migrate back to the Sargasso Sea, where they spawn and die.

Until recently, it has been generally accepted that the European eel comprised a single, randomly mating population, or panmictic stock (Schmidt 1925; Tesch 1977). A number of previous genetic studies (e.g. Pantelouris, Arnason & Tesch 1970; DeLigny & Pantelouris 1973; Avise, Helfman, Saunders & Hales 1986; Lintas, Hirano & Archer 1998) have not challenged the panmixia hypothesis. However, a more recent study (Wirth & Bernatchez 2001), using highly polymorphic genetic markers giving better resolution, provided evidence of genetic differentiation. The observed distribution of genotypes in this study were indicative of non-random mating and restricted gene flow among eels from different sampled locations, and were at odds with the concept of a single panmictic stock. Three broad groups: Mediterranean, North Sea and Baltic, and northern (Iceland) were identified. These findings have implications for the strategies adopted for the management for the European eel. The management of a panmictic stock would clearly require a co-ordinated approach across Europe to ensure an adequate escapement of silver eels overall. However, with growing evidence of stock structure, it becomes increasingly important to ensure that silver eel escapement is protected throughout the species range. It also suggests that it may be appropriate to restrict the transfer and stocking of elvers and eels, at least beyond the range of these stock groups.

In addition to the above, there are many other uncertainties pertaining to the biology and life cycle of the eel. Very little is known about the oceanic phase of the life cycle, and the little that is known is largely beyond the influence of management. It is thought that this phase is driven principally by density-independent processes (ICES 2001), and Knights (2003) has speculated that long-term oceanic and climate changes may be impacting on recruitment of anguillid species throughout the Northern Hemisphere.

For elvers and yellow eels there is enormous phenotypic plasticity in variables such as growth, sex differentiation, diet, maturation size and age, morphology and habitat shifts. There is evidence that factors such as growth rate, sex ratios, and size and age at maturation are influenced by latitude, and sex ratios have also been related to eel density (Tesch 1977; Krueger & Oliveira 1999; Oliveira 1999; ICES 2001). It is more likely that density-dependent processes predominate in the freshwater/estuarine phases, with production limited by the availability of suitable habitat or food (e.g. Vøllestad & Jonsson 1988; ICES 2001).

Status of stocks

There is little information on the population dynamics, catches and stock status of the European eel. However, the available data suggest that recruitment of glass eels has been falling for the last 20 years and appears to be at historically low levels (Moriarty & Dekker 1997; ICES 2002). Yellow and silver eel catches have also been falling in many parts of the species range over a similar time-scale (Moriarty & Dekker 1997; ICES 2000). Given the life cycle and relative longevity of the eel, declining recruitment will have a delayed effect on the densities of eel in freshwater systems and the resulting spawning escapement (Dekker 2003). Thus recent declines in recruitment could lead to a continuing reduction in the numbers of spawners and the recruitment of glass eels for at least another 10 years.

The precise cause of the current low level of recruitment is unknown, but it is speculated that changes in oceanographic conditions, possibly linked to climate change, may be the most significant factor (Moriarty & Dekker 1997; Knights 2003). Other factors, such as degradation of freshwater habitats, may also have affected eels in some areas, and barriers to upstream migration may have reduced the areas available for eels in comparison with historical levels (Moriarty & Dekker 1997; Knights & White 1998).

The European eel stock has also been affected by the introduction of the swimbladder parasite, *Anguillicola crassus* Kuwahara, Niimi & Itagaki, from Asia (Kirk 2003). The parasite appears to be widespread and high rates of infestation within populations and high levels of incidence within individuals have been widely reported (ICES 1997b). The presence of the parasite may lead to dysfunction of the swimbladder as a hydrostatic organ (Würtz, Taraschewski & Pelster 1996), cause reduced tolerance to stress (Molnár 1993), and can affect the eel's physiology and reduce its swimming speed (Sprengel & Lüchtenberg 1991). The presence of the parasite has also been implicated in some large-scale eel moralities in fresh water (ICES 1997b). The effect of this parasite on the eel's ability to migrate to its oceanic spawning grounds is unknown. There is no clear evidence for a significant effect on the transatlantic breeding migration (Moriarty & Dekker 1997), however, the impact could be considerable. This might therefore affect future levels of recruitment.

The precautionary approach and eel fisheries

In 1995, an FAO Technical Consultation on the Precautionary Approach to Capture Fisheries developed guidelines on management, research, technology development and species introductions in support of the implementation of the Code of Conduct for Responsible Fisheries (FAO 1995b). The FAO technical guidelines (FAO 1996), here termed 'the Guidelines', were aimed at governments, fishery managers, the fishing industry and all other interested parties to raise awareness about the need for precaution in fisheries management and to provide practical guidance on how to apply such precaution. The Guidelines also have many parallels in the United Nations Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (United Nations 1995). Although this agreement did not relate specifically to eels, it may be considered appropriate to apply the same management principles to other migratory, and indeed non-migratory, species.

The Guidelines call for '*consideration of the needs of future generations and avoidance of changes that are not potentially reversible*' and propose that '*harvesting and processing capacity should be commensurate with estimated sustainable levels*'. Thus the management objectives for European eel should be based around establishing long-term sustainable use of the eel stocks. More specifically both the FAO (1996) and UN (1995) suggest that managers should use the best available scientific evidence to determine stock specific limit and target reference points. Reference points have been defined as 'estimated values derived through an agreed scientific procedure corresponding to the state of the resource and of the fishery, which can be used as a guide for fisheries management' (ICES 1997a), and are generally used to define levels of fishing mortality or spawning stock. Limit reference points (LRPs) set boundaries intended to constrain harvesting within safe biological limits, while target reference points (TRPs) are intended to help meet management objectives. Thus reference points for eels should be set for individual management units, such as river catchments

(ICES, 2001), in order to provide a basis for assessing the status of stocks and determining the need for conservation and management actions.

Management actions may be triggered if the stock approaches or falls below a spawning stock limit, while a target might be used to determine a management action, such as establishing a quota (e.g. the predicted or estimated stock minus the target might indicate the maximum allowable catch). The probability of exceeding fishing mortality limits, or falling below spawning stock limits, should be low, although the actual probability considered acceptable by managers will depend upon the level adopted (Caddy & McGarvey 1996). Thus if the spawning escapement limit is set at a high level, it should be acceptable to allow the stock to fall below this level more frequently than if it had been set at a low level. Target reference points on the other hand are points to aim at and should not therefore be exceeded on average, instead the stock might be expected to fluctuate around the target. The use of targets may therefore provide a mechanism for trying to ensure that stocks exceed their limit reference points, taking account of stochastic processes and uncertainties about population dynamics, stock assessments and management procedures.

There is no universal reference point that is suitable for all fish stocks and a wide variety of different points have been proposed for different purposes (ICES 1997a). The United Nations (1995) proposed that the fishing mortality (F_{MSY}) which generates maximum sustainable yield (MSY) should be regarded as a minimum standard for limit reference points, and the spawning stock biomass that can yield the long-term average MSY (B_{MSY}) is suggested as a rebuilding 'target' for overfished stocks, although no specific spawning stock limit reference point is proposed. NASCO adopted S_{MSY} (the numerical stock that should give MSY) as the conservation limit for Atlantic salmon stocks (NASCO 1998), while other organizations have proposed different levels, albeit sometimes on an interim basis (e.g. ICES 1998).

A basic requirement for setting such reference points is that there is a relationship between the size of the spawning stock and the level of recruitment, since in the absence of such a relationship there would be little basis for determining whether a particular spawning escapement was more desirable than any other. The adoption of a precautionary approach dictates that, unless it can be scientifically demonstrated to the contrary, a relationship between stock and recruitment should be assumed to exist (ICES 1997a). Thus the absence of estimates of spawning stock and recruitment for European eels does not preclude the need to set reference points; rather a precautionary approach requires that when information for determining reference points for a fishery is poor or absent, provisional reference points should be set, and these should be revised as improved information becomes available through enhanced research or monitoring. This reflects the current position as it applies to eels. There are no grounds to suggest that a stock and recruitment relationship does not exist, but there are currently insufficient data to define such relationships for either the European (ICES 2002) or North American (ICES 2001) eel. Provisional reference points for eels will therefore need to be established by analogy to similar and better-understood stocks. Time series of population indices such as catch per unit of effort or survey data might be used to set preliminary limit reference points (ICES 1997a; Briand, Tain, Fontenelle & Feuteun 2003). The maximum index level might be used as an indicator of the unexploited biomass, and a limit reference point might be set at a proportion, say 30%, of this value (ICES 2002). Enhanced monitoring will need to be initiated to facilitate the revision and improvement of the provisional figures.

The Guidelines call for '*prior identification of undesirable outcomes and of measures that will avoid or correct them*' and note that '*where the likely impact of an activity on a resource use is uncertain, priority should be given to conserving its productive capacity*'. It is desirable that managers should determine how they will react to a problem before it occurs, and management strategies should therefore define the actions that will be taken if, for example, stocks approach or fail to meet limit reference points. Without such a predetermined decision structure there is a tendency for social and economic justifications to be used to water down or delay management actions. This will present particular problems for the management of the European eel because stocks are already in a depleted state. It will therefore be particularly important to ensure that objective judgements are made to determine the management requirements for stocks and fisheries.

The application of a precautionary approach requires that '*any fishing activities must have prior management authorisation and be subject to periodic review*.' A concern in this regard is that managers in many parts of Europe may currently be poorly placed to regulate and monitor eel fishing activities, due to only limited, if any, mechanisms for controlling effort or catches in eel fisheries. Providing an appropriate legislative framework, whereby appropriate controls can be introduced, within the context of a wider

European strategy, should therefore be a high priority for managers. The Guidelines also indicate that the implication of stocks approaching or failing to meet their reference levels is that corrective measures should be '*initiated without delay, and they should be designed to achieve their purpose promptly, on a timescale not exceeding two or three decades*'. Furthermore, where the failure of stocks to meet conservation requirements cannot be resolved quickly, there is a need to put a 'stock rebuilding programme' in place. There is now growing evidence that the European eel stocks have been in decline for a number of years (ICES 2002) and there is therefore an urgent need to ensure that adequate spawning stocks are being conserved. With a long-lived species like the eel, meeting the above timescale will present a particular challenge, and means that action needs to be initiated immediately throughout the species range. ICES (2002) has called for a recovery plan for the eel stock to be compiled and implemented as a matter of urgency and for the fishing mortality to be reduced to the lowest possible level until such a plan is agreed upon and implemented.

Both the FAO (1996) and UN (1995) identified the need to improve decision making for fishery resource conservation and management by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty. This is particularly important for eel fisheries both because of the general paucity of data and the widespread distribution of the European eel stock. Where the status of stocks is of concern, levels of monitoring should be increased to establish a better understanding of the status of stocks and the efficacy of conservation and management measures. There is also a need for full co-operation in eel research and monitoring throughout Europe.

The precautionary approach is being applied not only to fisheries management but to a wide range of other fields including environmental protection and technological developments. Thus, while the main thrust of the work of fisheries organizations, including those with responsibilities in the NE Atlantic such as ICES, NAFO and NASCO (ICES 1997a; NAFO 1997; NASCO 1998), has been the development of biological reference points for fish stocks, some have considered the wider implications of the precautionary approach for such issues as the protection and restoration of habitats (NASCO 1999). A range of factors, other than just fisheries, are involved in the decline of the European eel stock (ICES 2002), and action is required in many areas to improve or increase access to freshwater habitats (e.g. Moriarty & Dekker 1997; Knights & White 1998; ICES 2002). Thus the application of a precautionary approach to the management of eels will not only affect the regulation of fisheries, but should also relate to non-fisheries factors, such as the management of freshwater, estuarine and coastal habitats. It may also require attention to be paid to other activities such as aquaculture insofar as this can affect, for example, market forces, transfer of juvenile recruits and the possible introduction of diseases and parasites.

The FAO (1995b) also noted that if a natural phenomenon has a significant adverse impact on the status of living aquatic resources, action should be taken to adopt conservation and management measures on an emergency basis to ensure that fishing activity does not exacerbate the problems. ICES (2000) suggested that the decline in elver recruitment may be due, in part, to changes in oceanographic conditions and has expressed concern that the problem is likely to persist. While such changes may be beyond our control, management actions may be required to reduce exploitation or enhance stocks to counteract the effects of this natural phenomenon. A further concern is the potential for depensatory processes to operate at low stock levels (Liermann & Hilborn 1997), if, for example, silver eels find it difficult to find mates at low spawner densities in the Sargasso Sea. Thus, although the cause of the stock decline may be beyond our control, there may be a need for a disproportionate response to protect the stocks.

Finally the Guidelines call for the '*appropriate placement of the burden of proof*', and this requires a reversal of what has hitherto been common practice. Managers have traditionally faced strong socio-economic and political pressures to protect fishing interests, often leading them to seek clear evidence of a conservation need before they would introduce measures to protect stocks. The onus should now be placed on those wishing to exploit the stock, or increase potential impacts, to demonstrate that their activities are acceptable rather than on the managers to show that they will have adverse effects. This is particularly pertinent to the management of elver fisheries in parts of Europe. A 10-fold increase in the price of elvers to supply the eel farming industry in South East Asia has led to an increased demand for fishing licences in some recent years, despite the poor elver recruitment (ICES 2000). Allowing fishing effort to increase in such circumstances would not be precautionary and would contravene the principle that '*increases in capacity should be further contained when the resource productivity is highly uncertain*'.

Conclusions

The principles of the precautionary approach are directly relevant to the management of eel stocks, given the high level of uncertainty that persists about the status of the stocks and the biology of this highly complex, migratory species. There is widespread concern about the apparent decline in elver recruitment, and there is mounting pressure for action to safeguard this important resource. However, it is more likely to be many years before many of the scientific questions about eel population dynamics can be resolved, so there is a need to develop appropriate management approaches that take account of these uncertainties.

The application of a precautionary approach to the management of the European eel has a number of immediate implications. Managers need to agree on the management objectives for the stock on both a national and international basis. They also need to ensure that systems are in place to permit the appropriate regulation of fishing and other activities that may affect eel stocks. In addition, harvest strategies and decision structures should be developed to determine how fisheries will be controlled, taking account explicitly of uncertainties in assessment and management procedures.

Provisional biological reference levels should be established to provide an equable assessment of the status of stocks in all parts of Europe and to evaluate the need for management measures in all fisheries. The disparate nature of current fisheries may make it impractical to set fishing mortality limits, and so limits based upon silver eel escapement are most likely to be appropriate. In the absence of a stock-recruitment relationship for eels, threshold reference points (conservation limits) will need to be set on the basis of the best available information on the historical status of stocks and on information derived from other fish stocks. Interim reference levels might be based on estimates of the productive capacity of eels in different waters, but there is a need to undertake more research to develop more reliable reference points.

Of course, the absence of reliable scientific information on eel stocks should not be used as a reason for failing to implement conservation and management measures particularly as there is evidence that stocks are at low levels and may be declining. However, it is also important that monitoring of the eel stock should be enhanced and co-ordinated to improve our understanding of the status of stocks throughout Europe and the needs for management controls. The FAO (1996) and UN (1995) have highlighted the need to increase investment in research when information is uncertain or inadequate. Uncertainties in our understanding of biological systems may reflect both inadequacies in scientific knowledge and unpredictable stochastic effects. Even with the best scientific information there may be uncertainties due to random factors. However, in many situations scientific understanding of the systems being managed will be poor and this will add to our difficulties in predicting future events. In either case these uncertainties should be taken into account when selecting appropriate management options. When the scientific advice on an issue is highly accurate and comprehensive there may be little need for precaution in proposing measures to meet management objectives. However, where the scientific understanding is poor, as is the case for the European eel, there will be a greater need for precaution to take account of uncertainty.

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