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Report of the Workshop to Evaluate the Potential of Stock Enhancement as an Approach to Fisheries Management.

Copenhagen, 19-24 May, 1994.

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* General Secretary
ICES
Palægade 2-4
DK-1261 Copenhagen K
DENMARK

CONTENTS

1 INTRODUCTION

1.1 Terms of Reference

At the 81st ICES Statutory Meeting in Dublin (Ireland) in September 1993 it was decided (C.Res. 1993/2:28) that a Workshop to Evaluate the Potential of Stock Enhancement (Co-Chairmen: Ms J.G. Stottrup, Denmark and Mr T. Jakobsen, Norway) would be held in Charlottenlund, Denmark from 19-24 May, 1994 to:

1. define the objectives and options of stock enhancement.
2. identify biological, ecological and economic criteria for assessing the potential for stock enhancement.
3. recommend procedures for testing these criteria.
4. review current work in this field and identify priorities for future work.

1.2 Participation

The Workshop met in Charlottenlund from 19-24 May, 1994 with the following participants:

Dr J Addison	UK
Dr C Bannister	UK
Mr T Bjørnerem	Norway
Mr G Blackwood	Canada
Prof J Blaxter	UK
Mr C Burton	UK
Mr E de Cárdenas	Spain
Dr V Christensen	Denmark
Mr D Danielssen	Norway
Mr P Degnbol	Denmark
Dr J Giske	Norway
Mr J Goutayer	Spain
Dr B Howell	UK
Dr J Iglesias	Spain
Mr T Jakobsen (Co-Chairman)	Norway
Dr A Jensen	UK
Mr A Kristiansen	Denmark (Faroe Islands)
Dr P Larsson	Sweden
Ms G van der Meeren	Norway
Dr T Pedersen	Norway
Mr R Penney	Canada
Ms J Støttrup (Co-Chairman)	Denmark
Dr T Svåsand	Norway
Prof F Thürow	Germany

The following guests also participated:

Dr W Brugge	DG XIV, the Commission of the EU
Dr G Fabi	Italy
Dr A Laurec	DG XIV, the Commission of the EU

A full list of the names and addresses of members of the Workshop and guest participants is given in Appendix I.

1.3 Background

The relatively recently developed ability to rear large numbers of marine fish and shellfish larvae through to the less vulnerable juvenile stages has rekindled considerable interest in the prospect of enhancing exploited natural stocks with reared individuals. During the last decade or so numerous enhancement trials have been undertaken with a wide range of species throughout the world. Reports of the progress of many of these were presented at an international symposium on Sea Ranching of Cod and other Marine Fish Species held in Arendal, Norway in 1993 (Danielssen *et al.*, 1994). Some positive achievements were described. For example, it has been demonstrated for many species that reared individuals may survive and grow well in natural environments, although it was recognised that rearing and release methods may have an appreciable influence on performance. For many studies, however, a lack of evaluation of the results against defined objectives has made the potential for stock enhancement difficult to assess.

This conclusion was reinforced at the subsequent Theme Session on Implications of Stock Enhancement of Marine Organisms at the ICES Statutory Meeting held in Dublin during September 1993 and the need was recognised for a critical analysis of the potential for this form of fisheries management. Although the Workshop is primarily concerned with an evaluation of 'stocking' as a means of enhancing fisheries, some consideration is also given to forms of habitat manipulation, specifically artificial reefs, which may also involve stocking.

2 DEFINITION AND OBJECTIVES OF STOCK ENHANCEMENT

2.1 Definition

The term 'stock enhancement' is commonly used to describe attempts to enhance natural stocks by liberating fish or shellfish into the sea, though strictly it implies any measure which may lead to an increase in sustainable yield or stock size, including conventional stock management measures and habitat manipulation or improvement.

To avoid confusion with other forms of management, the Workshop prefers to use the generic term **stocking** to describe the *intentional release of reared or wild fish or shellfish with the aim of utilising the natural production of the sea.* This covers all of the objectives listed under 2.2.

A variety of terms have been used rather loosely to describe various stocking practices. The most common are ranching, augmentation, enhancement, introduction and addition (see for example Bannister, 1991). Although many may consider these terms to be associated with particular types of activity (for example, ranching may imply a greater degree of stock ownership than other terms) the Workshop considered that the various terms lacked precision and were not clearly distinguishable. It decided that there was little merit in attempting to devise more precise definitions, and retains the more general term only.

2.2 Objectives

The purposes of stocking have been specified in some detail for fresh-water environments in a report of an EIFAC Working Party (EIFAC, 1984) and discussed by Cowx (1994) in a recent paper on stocking strategies. A similar range of objectives would apply to the marine environment. The more common objectives proposed may be summarised as:

1. To increase yield from a fishery

2. To promote or accelerate the recovery of depleted or collapsed stocks

3. To ensure the survival of stocks threatened with extinction

4. To create new stocks either within or outside the natural geographical range of the species

3 CRITERIA FOR ASSESSING THE POTENTIAL FOR STOCKING

Setting up a stocking programme requires decisions about the following operational options:

- choice of geographical area, target species, and stock unit

- choice to restock existing habitat or to create new habitat

- choice of life history phase (eg larvae, juvenile, adolescent, adult) likely to maximise the benefits depending on production costs and survival factors

- choice of broodstock source (local or otherwise)

- choice of release strategy, depending on habitat, behaviour and predation

- choice of stocking level and programme duration

- choice of ownership, harvesting and management framework

Programme managers need to adopt a rigorous approach to the evaluation of enhancement projects, as stressed by Laurec (WD 1994) in his introductory remarks. Scepticism centres in particular on ecological and economic factors. From the ecological viewpoint it is usually assumed that natural populations are ultimately limited by some form of density dependent regulation. This could reduce or eliminate the benefits of a stocking programme, depending on its scale. From the economic vewpoint it may be difficult to determine whether production and stocking costs will be balanced or exceeded by the weight and value of subsequent recaptures. In the light of this, and experience from a variety of historical and present day enhancement schemes, the potential viability of a project should be carefully previewed in relation to clearly stated objectives, an assessment of relevant ecological, life history and operational questions, and appropriate monitoring strategies for demonstrating and assessing the nature of the outcome. The latter is particularly important : too many historical projects have ignored the need to show what the stocking programme has achieved.

A prior appraisal of the project should assess its suitability and potential success, based on the following criteria or questions :

3.1 Ecology

- Is current population size depleted and/or below the carrying capacity of the target area?
- Is natural recruitment reduced, or insufficient for the natural population to reach the carrying capacity ?
- Is there potential for habitat manipulation to increase carrying capacity ?
- Will stocking adversely affect other species, or the environment ?
- What are the risks that the reared stock will introduce disease ?
- Is it important or critical to maintain the genetic integrity of the stock ?

3.2 Life history

- How well does the target area provide for any specific habitat or environmental factors required for the survival of the target species ?
- What is known about regulatory mechanisms in this species or area ?
- What is known about migration ?
- What life history stage for release will best avoid complications from regulatory processes or migration ?
- Can the survival of reared fish set out in the wild be measured quantitatively and with sufficient precision to test for density dependence or carrying capacity effects ?

- Is the survival potential of reared fish and wild fish likely to be similar (see also section 7) ?

3.3 Rearing and releasing

- What is a realistic stocking level for the target species/area ?
- How many years of stocking are envisaged ?
- Can the target species be reared reliably to the required life history stage in sufficient numbers at sufficiently low cost ?
- Are the reared juveniles fitted for survival in the sea?
- Are suitable transport and release techniques available ?
- Can reared fish be distinquished from wild fish ?

3.4 Fisheries management

- Are the access rights and ownership provisions suitable for a stocking programme ?
- Are harvesting controls and technical management measures in existence, or required ?

3.5 Cost-benefit analysis

- Is there sufficient information to assess the financial viability of the project in terms of net present value over a realistic operational time scale, or to carry out a full scale cost-benefit analysis including quantification and allocation of the social benefits ?
- Do these analyses indicate whether a stocking programme is likely to be financially self-sustaining, or will require subsidy ?
- How do the potential costs and benefits of restocking compare with the costs and benefits of stricter management of the wild fishery ?

Regarding the latter topic, traditional fisheries management (defined as maintaining sustainable fisheries within viable ecosystems while maximising economic and social benefits) may be in some cases a more biologically realistic option than restocking, but it may lead to undesirable social consequences if quotas are imposed, vessels and crews laid off, or fisheries closed. A traditional fisheries management approach cannot of course re-establish extinct stocks, accelerate recovery beyond the natural potential, or increase recruitment beyond the natural potential.

4 CASE STUDIES

The degree to which the above questions and criteria have been met by historical and current stock enhancement experiments and programmes is illustrated by the case studies presented and reviewed at the Workshop. These are summarised in this section, and described in more detail in the appendix papers.

4.1 Roundfish

There has been increasing international interest in the enhancement of local marine fish stocks over the past decades. In the Pacific, about 30 marine fish species have been identified for stocking and in the Atlantic fewer than 10 (Danielssen et al., 1994). In 1990 the Norwegian government decided to initiate a nation-wide stocking programme with Atlantic cod as the marine fish species (the other species were Atlantic salmon, *Salmo salar*, Arctic char, *Salvelinus alpinus* and lobster, *Homarus gammarus*). Similar projects have also been initiated in other Nordic countries.

Cod stocking in Norway.
Early work in the first decades of this century showed no demonstrable effect on recruitment when cod yolk-sac larvae were released in large numbers in an attempt to augment the coastal fishery (Tveite, 1971). Later success in rearing relatively large numbers of 0-group cod led to the release of older stages on the Norwegian and Danish coasts (see Danielssen *et al.*, 1994; Svåsand, WD 1994). The main conclusions were as follows:

1. Successful large-scale production of O-group cod in Norway.

2. Successful marking has been achieved by using external floy tags, alizarin or oxytetracyclin to mark otoliths and vertebrae and genetic markers.

3. After release reared cod reverted towards the wild fish in terms of diet and anti-predator behaviour within a few weeks. Reared and wild cod had similar growth rates in the sea.

4. Cod tagged and released outside the spawning seasons in shallow coastal fjord areas were recaptured close to the release site. Larger displacement distances have been reported from Limfjorden, Denmark (Støttrup *et al.* 1994).

5. Increased survival with increased size at release was reported, and indications of density-dependent mortality in the pre-recruit period were found. Natural mortality seems to stabilize at the end of the 1-group stage. The most probable reasons for the pre-recruit mortality in the investigated locations in western Norway are cannibalism and predation from pollack. In northern Norway, cannibalism and predation from Cottidae are most important.

These experiments suggest that there was no excess carrying capacity in the investigated fjords at the time of the experiments. Field surveys, regression models and dynamic ecosystem models indicate that carrying capacity increases towards the outer coastal areas.

This hypothesis should be tested by further experimental releases.

Proposed cod stocking programme in Newfoundland.
The Newfoundland cod stock for many years was of the order of 1 million tonnes. At present it is 20 000 tonnes with little evidence of recruitment; the fishery is closed and thousands of fishermen have not been able to redeploy. One option is to rest the stock in the hope that it will recover by natural recruitment. The time required is unknown and depends on the appearance of one or more good year classes.

The following more positive approaches are being considered by the Canadians:

1. to enhance the fecundity of wild cod by rearing wild juvenile cod (about 1000 MT/yr) captured in inshore areas, feeding them intensively for one or two seasons, then releasing the now 'growth-fecundity enhanced' fish nearby.

2. to strip eggs from a captive broodstock of some 5000 females (5 billion eggs), held in a shore-based facility, and release the eyed eggs into a highly eutrophic coastal area.

Initially, both initiatives would be tested on a reduced pilot scale level to allow confirmation of various assumptions made in the methodology.

The likely success of such measures need to be evaluated with the following considerations in mind:

1. marine fish are highly fecund with an annual production of tens of thousands to millions of eggs.

2. mortality is enormous; mortality rates are of the order of 10% per day for eggs and larvae. On average a single female cod with a fecundity of 1 million eggs will produce two recruits.

3. earlier work on release of cod and plaice eggs was never shown to improve recruitment (Shelbourne, 1964; Tveite, 1971).

4. at low spawning stock biomasses the failure of recruitment may not be due to lack of eggs but the inability of the spawners to aggregate at the spawning time, or the inability of the larvae to exploit their trophic environment (mismatch).

The results of the Canadian experiments will be an excellent test-bed for the value of stocking a high seas fishery. However, the history, past and recent, of stocking offshore finfish populations by release of eggs, newly-hatched larvae or 0-group indicates:

1. recruitment increase is unlikely,

2. if it occurs it might be difficult to demonstrate given the huge annual variations in year-

class strength

Cod stocking in other areas
Consideration was given to cod stocking in the Baltic Sea (Thürow WD 1994). The failure of recruitment may be due to any or a combination of a variety of factors (such as abiotic conditions, eutrophication, availability of food) and more precise information on the factor/s affecting recruitment of this stock need to be compiled in order to be able to assess whether or not there is a potential for enhancement through stocking.

In Sweden, stock enhancement experiments with Baltic cod in the Bothnian Sea have been initiated (Larsson & Pickova, 1993). The low salinity (<7‰) precludes cod from breeding in this area and recruitment occurs only when large year-classes are produced in adjacent waters; the Main Basin. The topography of the release sites (various-sized banks, 20-50 m deep surrounded by deeper waters), abundance of prey and scarcity of predators suggest that there may be a potential for enhancement of this stock through release programmes (Larsson & Pickova, 1993).

4.2 Flatfish

Mass releases of finfish have been practised as an approach for stock enhancement in Japan during the past 30 years with the Japanese flounder (*Paralichthys olivaceus*) figuring prominently in these exercises. Significant enhancement of the target populations have been claimed (Fukusho, 1993), although convincing evidence of this has yet to be produced. The economic viability of the Japanese flounder release programmes was appraised by Sproul and Tominaga (1992) who concluded that post-release survival was the major factor determining the economic benefit of the release programme.

The Danish stock enhancement programme.
The century-old tradition of releasing fish such as trout (*Oncorhynchus mykiss*), salmon (*Salmo salar*), pike (*Esox lucius*), eel (*Anguilla anguilla*), whitefish (*Coregonus lavaretus*) and pike-perch (*Lucioperca lucioperca*) by the fisheries organisations and sports fishermen has expanded during the more recent years into the release of truly marine species such as cod and flatfish species for which the rearing technology has been developed. Jointly funded by the government and fisheries organisations until 1993, the Danish freshwater and marine stocking programmes have since been financed entirely through licences for recreational and sports fishermen. These funds are administered by a committee within the Ministry of Fisheries, where the fisheries organisations are also represented.

- *Plaice transplantations*
During the first half of this century transplantations of plaice from an area of high density to one of low density resulted in improved growth rates of the transplanted fish and were of benefit to the local fishermen, but the cost of the exercise was too high to render this an economically feasible venture (Bagge, 1970). An attempt to improve the Kattegat stock by transplanting North Sea plaice to the Kattegat was also aborted, since the results from the recaptures showed a migratory behaviour towards the Skagerrak and the North Sea (Stæhr & Støttrup, 1991).

- *Flatfish releases*

The Danish marine stocking programme is still in its early stages and is primarily involved with research to evaluate the effects of mass releases of flatfish (and cod) as one approach for compensating for the decline in fishery yields. The releases are of reared fish of which around 30% are tagged. Since 1989, 402,000 turbot (*Scophthalmus maximus*), 250,000 plaice (*Pleuronectes platessa*) and 7,000 flounder (*Platichthys flesus*), as well as 36,000 cod (*Gadus morhua*), have been released.

Research is focused on the potential for flatfish stock enhancement based on the theory that recruitment of 1-year olds may be limited by the availability of appropriate nursery areas for newly-metamorphosed fish so that resources available for older fish may be under utilised. Further, releases are limited to small populations where the release of 1-year old fish may comprise a minimum 1% of the wild natural population of the same age group. In most cases, the natural population has had a recent history showing a drastic decline in recruitment to the fisheries due either to severe fishing pressure or eutrophication or a combination of both.

Research directed towards the evaluation of the effect of mass releases of marine fish comprises of laboratory and field research and relates to the development of tagging techniques as well as tag-recapture studies. An international project involving Sweden, UK and Spain, as well as Denmark, has been initiated to further this work. The main priorities are:

1. The development of tagging techniques, including internal and external markers, for different sizes of fish and different species.

2. An evaluation of the adapatability of reared fish to the natural environment. Experimental and field studies will be conducted to examine short- and long-term adaptation and to compare growth, migration and condition in released and wild fish.

3. To examine, through tag-recapture studies, the natural mortality of different life stages of released fish and to evaluate the benefits of releases to the fishery in relation to the size and time of release, the exploitation pattern and effort.

4. To examine migration and integrate this aspect in existing fish population (single species) models.

5. If feasible, to examine the effect of releases on natural populations.

A substantial part of the work also involves a detailed evaluation of the release sites, including biological features, environmental characteristics and fishery statistics.

More active compilation of data on the fisheries population has recently been initiated in cooperation with local fishermen. In addition, a qualitative and quantitative study on the bottom fauna in 2 specific sites in relation to fish species and their natural prey has been initiated and the results will be assessed in relation to future work on the carrying capacity of a site for the release of fish of specific sizes.

The work on marine stock enhancement in Denmark is in its initial stages and few results are as yet available. However, besides an evaluation of the potential for enhancement and providing possible approaches for optimisation, the studies in progress may make a valuable contribution to our understanding of pre-recruit processes, especially natural mortality of 0- and I-group stages. They may also serve as a tool to provide better information on population dynamics and recruitment of flatfish to the fishery which can be used in more rational fishery management.

Although few tangible results have been obtained so far, the increasing co-operation with local fishermen, their increasing involvement with releases and site evaluations has helped improve dialogue between biologists and fishermen and paved the way for future co-operation on fishery management.

4.3 Lobsters

Since the late 19th century homarid lobsters have been cultured under hatchery conditions, and hatchery-reared *Homarus gammarus* and *H. americanus* have been released into the wild on many occasions in Europe and North America respectively. In these early programmes the importance of possible density-dependent processes had not been considered, and it was simply assumed that increasing the numbers of larval or juvenile lobsters would consequently enhance the stock. Most of these early programmes were terminated because natural production was considered to be very much greater than any potential hatchery production, and because there had been no demonstrable success of such stocking experiments. Until the 1980s, however, little attempt had actually been made to evaluate the success of these experiments, mainly due to a lack of a suitable tagging method to discriminate between hatchery-reared and natural stock. These early stocking experiments are reviewed by Addison and Bannister (1994), and summarised in reports to this Workshop (Addison and Bannister, WD 1994; Burton *et al.*, WD 1994)

Recent experiments in Europe have since made use of coded wire microtags to identify hatchery-reared lobsters, and coupled with controlled release of juvenile lobsters by divers on suitable substrate and detailed recapture monitoring, a more rigorous approach has been developed to evaluate the feasibility of stocking lobster fisheries. From the biological viewpoint the initial results from experiments in four different sites in the UK as well as in Norway have been encouraging. Substantial numbers of hatchery-reared juvenile lobsters have survived to recruitment in the wild 4 to 6 years after release, have formed part of the catch in commercial fisheries, and surviving females have matured and carry eggs. These recent stocking experiments have therefore produced important information concerning the time taken to reach maturity and to recruit to the fishery, variations in growth rate both within and between cohorts, and site fidelity, enabling significant advances to be made in understanding recruitment processes. (Similar stocking experiments using coded wire microtags are being undertaken in Ireland, but only preliminary results are so far available).

In order to demonstrate successful enhancement of lobster stocks, we need to evaluate the survival of these hatchery-reared lobsters in the wild. Bannister *et al.* (1994) have made the critical step by assessing the survival rate of hatchery-reared lobsters in the wild in England using ancillary tag-recapture experiments. They estimated that between 50% and 80% of cohorts of hatchery-reared lobsters have survived (Bannister *et al.*, WD 1994).

The question remains to be asked whether hatchery-reared animals actually enhance the stock or simply replace natural recruits (Bannister and Howard, 1991). Studies of lobster populations suggest that under certain circumstances habitat may be a limiting factor for juvenile lobsters in some fisheries, but it seems unlikely that density-dependent mortality due to habitat limitation would operate at the levels of juvenile lobster abundance at which we would consider implementing stocking programmes. This problem requires further consideration and recent stocking experiments in Norway may be able to address this problem (G. van der Meeren, WD 1994).

Lobster scientists are now looking ahead to the potential applications of these results. This involves deciding on the scale of stocking, and the corresponding size of hatchery required to enhance a typical coastal lobster fishery. It also involves investigating the likely economic viability of such projects. Preliminary appraisals emphasise that restocking is a long term venture. It takes four to six years for a juvenile lobster to reach legal size, and it will take nine or ten years to establish the fishable size range. At current production costs and market prices, a financial assessment suggests that a lobster stocking project may require to recapture 20-30 % of the hatchery stock over a 25 year pay-back period in order to break even. If production costs can be reduced, the economic viability may be considerably more encouraging. One way of achieving this cost improvement may be to release lobster juveniles earlier, at stage VI to VIII, and a trial programme with this size of lobster is in progress in Scotland.

To conclude, the lobster stocking trials have shown conclusively that hatchery-reared lobsters can survive in the wild up to nine or ten years after release on to suitable habitat at a variety of sites. The MAFF experiments have also attempted to measure the survival rate on the ground, and to carry out preliminary financial appraisals of the likely economic viability of small scale projects suitable for typical coastal lobster fisheries in the UK. It is felt that the time is now right to apply the present techniques in a local lobster fishery which has been substantially depleted by fishing, in order to assess the real world economics of such a venture. This is being done in Norway where large-scale releases of lobster juveniles have been carried out in cooperation with a small island community (Kvitsøy) and the local Fisherman's Association. The wild stock is nearly depleted with an annual catch of less than 1 t, less than a tenth of that 40 years ago. About 130,000 juveniles were released between 1990 and 1994 and the fishery in the area is now being systematically monitored to evaluate the success of the operation (G. van der Meeren, WD 1994). Trials of this nature are also being developed in the Republic of Ireland, where juvenile lobsters from the Shellfish Research Laboratory at Carna, County Galway, are being released by fishermen's groups in Smerwick Harbour on the west coast, and at Wexford on the east coast (J Mercer *pers. comm.*)

4.4 Artificial reefs

Artificial reefs (defined as man-made habitats placed intentionally in the marine environment) may increase carrying capacity by introducing additional structure into the environment (Jensen, WD 1994).

Japan are the world leaders in artificial reef technology for commercial fisheries enhancement and have been creating artificial reefs from 1789, and probably before this date. Currently the Japanese are in the third phase of artificial reef development, that of creating entire fishing grounds where there had been none before.

In the USA the reefs programmes of many states are run for the benefit of recreational sports fishing, SCUBA diving as well as commercial fishing, waste disposal and environmental mitigation. American experience dates back over 100 years and a wide variety of materials have been used from concrete to stabilised Pulverised Fuel Ash (PFA) to "materials of opportunity" such as ships and train carriages

Elsewhere in the world artificial reefs have been developed locally according to requirement using materials judged to be suitable. Australian artificial reefs have been created from "materials of opportunity" such as tyres and ships. Such reefs have been used primarily as a location for recreational angling with some SCUBA diving also taking place. The Maldives have utilised concrete structures to repair coral reefs damaged by dynamite fishing. Artisanal artificial reefs have been used in India as part of a programme to boost local fishery captures.

From the 1960s there has been a wide range of interest in the utilisation of artificial reefs in Europe. Poland, Russia and Finland are studying the potential of artificial reefs to act as biofilters near aquaculture sites. The UK and Italy have an interest in the environmental acceptability of stabilised waste materials such as Pulverised Fuel Ash from coal fired power stations. Researchers in Italy, Spain, France and Israel have programmes looking at the ability of artificial reefs to improve the efficacy of commercial fin-fisheries, whilst Spain and Italy have interests in mollusc culture on artificial structures. In Spain and Italy artificial reefs are also widely used to protect coastal areas or *Posidonia oceanica* beds against trawling. The UK, Italy and Israel are at varying stages of investigating the use of artificial reefs for lobster stock enhancement whilst Holland, Portugal, Turkey, Spain and Monaco have reefs placed to study epifaunal colonisation and/or for nature conservation.

Artificial reefs may be used for stock enhancement in a number of ways:

1. to increase the amount of available habitat where appraisal suggests:
   (i) there is a potential to increase biomass, and
   (ii) therefore there is potential to enhance stock,

2. to test hypotheses of carrying capacity and habitat utilisation in an experimental system,

3. prevent, and/or mitigate, actual or predicted negative impacts of, say, fishing gear on

an area valuable to stock enhancement,

4. supply habitat for a species that is otherwise not available.

It appears that only 3 countries, Canada, Israel and the UK have focused attention on artificial reefs as a specific habitat for lobsters. In the UK, studies have been in progress since 1988 on an experimental reef placed in Poole Bay on the central south coast of England. Within 3 weeks of deployment, lobsters (*Homarus gammarus*) were present on the reef. Tagging studies show that lobsters have found the artificial reef a suitable long term habitat, the longest period of residence stands at 1050 days. Conventional tagging of sub legal size (<85mm CL) lobsters in the nearby Poole Bay fishery has revealed that lobsters in the Poole Bay area do not undertake any seasonal migration, and that most movements averaged over time are less than 4 km in magnitude. Diver observations and evidence from pot caught lobsters suggests that the Poole Bay artificial reef can support all aspects of the lobsters benthic life cycle. This would suggest that the stocking of an artificial reef with hatchery reared juvenile lobsters may be a viable stock enhancement exercise. The survival of such juveniles in the wild has been shown by work in the UK and Norway.

In an European context, Mediterranean research shows that artificial reefs can aggregate finfish in commercially useful numbers. Harvesting is possible by lining within the artificial reef or by gill netting around its periphery. This work highlights a serious shortfall in global artificial reef research which has yet to resolve the question of wether artificial reefs can be net producers of fishery biomass. It appears at present that this question will be species and locality dependent. Some observations, such as of the abundance of benthic eggs, juveniles as well as spawners, indicate that artificial reefs might contribute to an increase in the biomass of some fish and cephalopod species. The main problem, however, is to quantify the increase in biomass because of the continuous exchanges between the reef and the surrounding open sea.

Economically, Mediterranean artificial reefs have produced commercially significant production of mussels, well in excess of deployment costs. It appears feasible to produce a multipurpose reef with benefit to commercial stock exploitation and recreational interests such as angling and recreational SCUBA diving.

5 CONCLUSIONS FROM THE CASE STUDIES

The long history of attempts to rear and release various life history stages of cod, flatfish and lobster have culminated in the recent case studies described in the last section. Techniques have reached the point where it appears to be possible to rear substantial numbers of juveniles in the hatchery, transport them to a target area, and release them into the wild.

The Norwegian cod programme included extensive preliminary studies of the natural ecology and behaviour of juvenile fjord cod, and has measured the survival of reared cod released into the wild. The cod programme has demonstrated the feasibilty of the approach, but the results also showed that in years when carrying capacity was reduced by poor plankton abundance, high mortality rates reduced abundance to pre-stocking levels. This highlights the importance of understanding the cause, frequency and scale of carrying capacity fluctuations in relation to stocking levels in fjord areas. Carrying capacity increases towards the outer coastal areas, but results to date do not permit any conclusions about the likely viability of cod stocking in these areas.

The most extensively studied flatfish in recent years has been the Japanese flounder, *Paralichthys olivaceus*. Survival of released juveniles has been demonstrated, although this appears to be less than that of the resident population. Enhancement of local populations has been claimed but not unequivocably demonstrated. In Europe, transplantation experiments demonstrated improved growth rates of transplanted fish but concluded that this practice was unlikely to be economic. Current programmes are directed towards a rigorous examination of the feasibility of using reared fish to enhance stocks of several species, principally turbot (*Scophthalmus maximus*) and plaice (*Pleuronectes platessa*).

For lobster, present experiments in Europe provide clear cut evidence that hatchery-reared lobsters deployed onto suitable habitat can survive in the wild in significant numbers to recruit to commercial catches. The MAFF experiments on the English east coast show that it is possible to obtain data facilitating preliminary estimates of abundance and survival of hatchery-reared stock, on the basis of which tentative economic calculations have been carried out. Several of the most important criteria for pursuing a successful stock enhancement programme have clearly been met, although it is still too early to say that this approach can make a significant economic and social impact. Furthermore, carrying capacity experiments were not included in these studies, and it can only be inferred that hatchery-reared survivors have augmented rather than substituted for the natural stock in the fishing area. The carrying capacity and economic aspects require a substantial commercial-scale trial with a depleted stock in an area socially dependent on lobster fishing, and preliminary hatchery and operational specifications have been initiated in preparation for such an event.

The simultaneous studies on lobster on the small experimental artificial reef in Poole Bay show that a reef can successfully attract and retain a resident population of adult and adolescent lobsters for substantial periods of time, on the basis of which trial stocking and economic calculations have been undertaken. There is scope to explore the application of these results to coastal defence reefs, and related structures, although again it is too early to say whether this can be done at a scale large enough to have significant fishery or social benefit. Future artificial reef studies may also facilitate investigation of methods for estimating the carrying capacity of lobsters.

6 CARRYING CAPACITY

This section provides background information on the important topic of carrying capacity, (K), originally defined in the Lotka-Volterra model of bounded population growth as the number of individuals of a species that may be sustained by a particular ecosystem or habitat. This is represented by:

$$N_t = N_{t-1}\, e^{\,r[(K-N)/K]}$$

where N_t and N_{t-1} are number at time t and t-1 and r is the intrinsic population growth rate. Applied to a population, K is a function of body size (or age) distributions and depends on competition for food (by other species or by different age groups of the same species), predation, space and shelter.

K is defined in relation to survival of individuals (rate of change of population size). However, at the individual level, densities near or above carrying capacity will lead to reductions in somatic growth, not only in survivorship. This relation is not expressed in the Lotka-Volterra model. Carrying capacity may therefore not be the only habitat quality descriptor we should use. Life history theory indicates that individuals will be sensitive to both mortality risk and somatic growth rate, and their behaviour will tend to balance these forces so that a reduced growth potential may lead to higher predation mortality. We should therefore assess mortality rates and individual growth potentials (Walters and Juanes 1993, Salvanes et al. 1994).

K is not a static parameter; it varies on a seasonal or year-to-year basis and depends on such factors as the advection of food from other areas as a result of residual currents or wind. K may be particularly variable when the rate of external food supply is larger than or similar to the local prey production, as is common for coastal zooplanktivores. K is probably more stable for phytoplanktivores (e.g. bivalves) and piscivores. While seasonal and interannual variations in K may predominantly be due to advection, eutrophication (nutrient supply from river discharges precipitation) may have a gradual and long term effect on K.

It is desirable to assess K in order to evaluate the potential of an ecosystem/habitat to carry an increased population of a species. Ecosystem models including trophic structure and the variables potentially impacting K, may be used for assessing both the variability in K and the relative importance of each underlying variable (Giske, WD 1994, Giske *et al.*, 1991, Salvanes *et al.*, 1992). This theoretical approach to predict K of an environment should be pursued in parallel with an empirical approach, as the theoretical is both more general, will give basic results earlier and at a far lower cost than a pure empirical approach. In more stable systems, this may be done by modelling trophic flows, energy requirements, growth and mortality, for example as in ECOPATH (Christensen & Pauly, 1992, see also Christensen, WD 1994) if adequate input data are available.

There must be an interplay between modelling and empirical studies, in that observations may show what is important to model, and models may indicate which variables should be monitored. The ecological models can indicate the main factors controlling the carrying capacity, and suggest the "best" areas. This has been done for cod in western Norway, and it is suggested that open coastal areas have a larger potential carrying capacity than closed fjords. However, such a hypothesis has to be tested by large scale releases. Peterman (1991) lists five principles which will improve the reliability of the conclusions. These are:

1. A testable hypothesis
2. Temporal replications on the same stock.
3. A control stock/area
4. Large enough sample size to have a high probability of detecting effects, if effects occur.
5. Spatial replications.

Mortality, migration and growth, both in the pre-recruit period, and after recruitment to the fishery have to be studied, since these are potentially dependent on density and carrying capacity. Many fish stocks show year-to-year variations in growth rate and, at least in past years, signs of density-dependent reductions in growth at high stock biomass (Cárdenas, WD 1994). For areas where reliable fisheries statistics are available or can be obtained, it is possible to use traditional fisheries assessment methodologies to study the effect of stocking (which can be considered to be recruitment) upon subsequent yield. It can be added that the traditionally used age-based methodologies may be too costly for use in stock enhancement programmes as the questions posed in stocking do not call for full-scale biological assessment. Therefore, simpler size-structured methodologies should be considered, e.g. in the form of growth and mortality models or length-based VPA.

Predation (and cannibalism) are the main mortality factors in the pre-recruit period, and this mortality is often dependent on the carrying capacity of the area. In years with low carrying capacity, growth might be low and predation rates high. Increased predation rates can therefore mitigate a limited carrying capacity and adjust the number of recruits according to the current carrying capacity.

It is also important to evaluate effects of stocking on the wild stock, competitors and prey species.

Finally, the yield per recruit has to be calculated. This will not be constant but may vary according to carrying capacity, stock sizes (prey, competitors, target species), and the exploitation pattern.

7 FITNESS OF RELEASED INDIVIDUALS

If a restocking programme is to succeed it is clearly desirable that hatchery-reared animals are as fitted to survive as the natural stock, and also that there are no other genetic disadvantages arising from the use of hatchery reared animals. Salmon enhancement programmes, for example, have given rise to considerable concern about the likely genetic impact of rebuilding stocks to a level where the gene pool is dominated by animals of hatchery origin (see, for example, Hansen and Jonsson, 1994). A survey of the literature reveals that for fish there are many well-documented examples of morphological and behavioral differences between wild and reared individuals (Blaxter 1975; Svåsand 1993; Howell, 1994). It is, however, important to distinguish between (Svåsand 1993):

a) short term differences in behaviour caused by lack of acclimatization and stress caused by transportation and release into a new environment, and

b) lasting differences in phenotype and behaviour caused by the rearing environment.

For both groups, something can be done to reduce or diminish the differences between reared and wild individuals. For the first type (a), acclimation to the release environment, feeding, and predator training will often give positive effects, and this might be a good investment in stocking programmes.

Lasting differences (type b) might be caused by a lack of, or unnatural, stimuli during development. To normalise these differences, we must look at the rearing environment. One example is the rearing of lobsters where the use of substrate in the rearing boxes produces lobster fry with normal claws.

The possible effects of releasing deviant individuals depends on the species and the strategy for the stocking programme. If the aim is a "put and take fishery", it is not a strict demand that the reared individuals should resemble wild conspecifics. In such cases, it is more important to ensure a high return rate.

In releases where the goal is to enhance overfished populations, as with lobster stocks in Norway, the consequences of releasing deviant animals might be serious. In such cases strict demands must be made of the individuals that are to be released. The broodstock should be taken from the release area, and the size of the broodstock should be large to ensure that rare alleles are incorporated in the broodstock. The reared individuals must be as like wild stock as possible both in the juvenile period and when recruiting to the spawning stock. Measures of reproductive success are therefore important. This might be testable using genetically marked individuals (e.g. Nævdal 1994). In the case of any future lobster re-stocking programmes in the UK, the decision has already been taken to use broodstock of local origin wherever possible, but the question of whether the resulting progeny are likely to be genetically unfit in some way as a result of being reared in the hatchery has yet to be fully examined. This is an important question for the future.

8 ECONOMICS

The Workshop emphasised the need to undertake a preliminary financial appraisal and cost-benefit analysis to establish the credibility of a project based on existing information, or, in the case of a pioneering experiment, to preview the kind of information which should be obtained during the experiment. The financial appraisal will consider production costs (hatchery construction and start-up costs, hatchery running costs, and animal production costs), fishery costs, and potential revenue (catch and price). It will assess how, with these costs, the net present value of the investment depends on the survival and recapture rate of the stock, the duration of the project, and the discount rate. A sensitivity analysis of this kind may provide some objective targets for the project e.g. to increase or decrease the number of animals released; to reduce production costs by, say, increasing efficiency or changing the life history stage being released; or to attempt to obtain a critical minimal target recapture rate. The financial appraisal may be accompanied by a cost benefit analysis incorporating the political, social, recreational or tourism benefits of the project, and the allocation of the benefits among different user groups.

9 CONCLUSIONS

1. The 3 main options for enhancement are fisheries management, stocking and/or habitat manipulation.

2. Stocking should be regarded as a supplementary management tool and not as an alternative.

3. There are as yet no examples of quantitative methods being widely used for estimating whether any increase in yield has resulted from stocking, but recent lobster studies have demonstrated that hatchery-reared stock has survived long enough to be caught by fishermen, and the MAFF experiment on the east coast of England has developed a method for estimating their abundance and survival.

4. Effective enhancement of large, offshore fish stocks by stocking is presently not considered feasible because of high costs and technical and assessment limitations.

5. Restocking localised stocks which support recreational fisheries may be viable because of the high value of the harvest and associated economic activities.

6. Re-establishment of extinct or near extinct populations by the maintenance of a captive broodstock might maintain biodiversity, but may only be economically viable in localised areas. (However, the maintenance of a Baltic cod broodstock for the release of juveniles in the Bothnian Sea, may be one example where this may be feasible).

7. Recent stocking experiments have shown:

    - The survival, growth and behaviour of reared cod was similar to that of wild cod in Norwegian fjords. These experiments however, suggest that there was no excess carrying capacity in these situations, so that enhancement of the resident population was not demonstrated. Ecological models and field data, however, indicate that stocking may be more effective in more open coastal areas where carrying capacity is greater.

    - Enhancement of lobster stocks in natural habitats by stocking appears to be technically feasible and there is a potential for economic viability if production costs are reduced.

- Danish plaice transplantion experiments demonstrated improved growth rate of transplanted plaice, but this was insufficient to justify the cost of the exercise.

- Enhancement of bivalves by artificial habitats is technically feasible and economically viable.

- Artificial reefs attract and retain resident populations of lobsters, and some fish species, but may be costly to deploy at a size relevant to fishery operations. There is scope, however, to develop the artificial reef concept through the customisation of sea-defence structures.

8. Stocking may have additional benefit as a:

   - method to study ecology and behaviour of organisms

   - means of experimentally perturbing the ecosystem,

   - as a contribution to solve regional and social problems.

9. Scallops, abalone and sea-urchins were mentioned as potential candidates for stocking purposes, but no discussion of these organisms was included in the workshop discussion.

10 RECOMMENDATIONS

There is still considerable scope to :

1. develop **methodologies** to evaluate the effect of stocking and artificial reefs based on biological, economic, social and legal considerations.

2. undertake experimental studies quantifying carrying-capacity, survival of hatchery-reared organisms, density-dependent mortality, migration, predator-prey interactions and growth.

3. develop models of common interest to stocking and traditional fisheries management. These should include age and size information, dynamics of 0- and 1-group stages, carrying-capacity related to size and age, and migration effects.

11 WORKING DOCUMENTS ANNEXED TO THE REPORT

Addison, J.T. and Bannister, R.C.A. Lobster stock enhancement experiments. I. Historical perspective 1850-1980. WD 1994

Bannister, R.C.A., Addison, J.T. and Lovewell, S.R.J. Lobster stock enhancement experiments. III. Estimating survival and future fishery applications. WD 1994

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13 APPENDICES

13.1 List of addresses of members and guests.

<u>Members</u>

CANADA

Mr. Glen Blackwood,
Gvt. of Newfoundland and Labrador
Department of Fisheries
P.O. Box 8700
300 Strawberry Marsh Road
St John's
Newfoundland A1B 4J6
Canada

Dr. Doug Hay
Pacific Biological Station
Nanaimo, B.C.
Canada V9R 5K6.

Mr. Randy Penney
Department of Fisheries & Oceans
P.O. Box 5667
St. John's
Newfoundland A1C 5X1
Canada

Dr. Chris T. Taggert
Canada Dept. of Fisheries & Oceans
Northwest Atlantic Fisheries Centre
P.O. Box 5667
St. John's
Newfoundland A1C 5X1
Canada

DENMARK

Dr. Villy Christensen
International Center for Living Aquatic
Resources Management
North Sea Centre
Box 101
9850 Hirtshals
Denmark

Mr. Poul Degnbol
Danish Institute for Fisheries and Marine Research
North Sea Centre
Box 101
8950 Hirtshals
Denmark

Ms. Josianne G. Støttrup
Danish Institute for Fisheries and Marine Research
North Sea Centre
Box 101
8950 Hirtshals
Denmark

DENMARK (FAROE ISLANDS)

Mr. Andras Kristiansen
Fiskirannsóknarstovan,
Nóatún, P.O.Box 3051
FR-110 Tórshavn
Faroe Islands.

GERMANY

Dr. Otto Rechlin
Institut für Ostseefischerei
An der Jägerbäk 2
D-18069 Rostock-Marienehe
Germany

Prof. Dr. Fritz Thurow
c/o Bundesforschunganstalt für Fischerei
Aussenstelle Kiel
Wischhofsstrasse 1
D-241148 Kiel
Germany

ICELAND

Dr. Bjórn Bjórnsson
Marine Research Institute
P.O. Box 1390
Skulagata 4,
IS-121 Reykjavik
Iceland

IRELAND

Dr. John Mercer
Shellfish Research Lab.
Carna,
Co. Galway
Ireland

NORWAY

Mr. Trygve Bjørnerem
Fylkesfiskarlaget Sør
Postboks 144
6401 Kristiansand
Norway

Mr. Didrik S. Danielssen
Institute of Marine Research
Flødevigen Marine Research Station
N-4817 His
Norway

Dr. Torstein Pedersen
Norwegian College of Fishery Science
University of Tromsø
Dramsveien 201
9037 Tromsø
Norway

Dr. Jarl Giske
University of Bergen
Department of Fisheries and
Marine Biology
High Technology Center
N-5020 Bergen
Norway

Mr. Tore Jakobsen
Institute of Marine Research
P.O. Box 1870 Nordnes
5024 Bergen
Norway

Ms. Gro I. van der Meeren
Institute of Marine Research
Austevoll Aquaculture Research Station
N-5392 Storebø
Norway

Dr. Erlend Moksness
Institute of Marine Research
Flødevigen Marine Research Station
4817 His
Norway.

Dr. Terje Svåsand
Institute of Marine Research
P.O. Box 1870 Nordnes
N-5024 Bergen
Norway

SPAIN

Mr. Enrique de Cárdenas
Inst. Espãnol de Oceanografía
Centro Oceanografico de Santander
Apto. 240
39080 Santander
Spain

Mr Juan J. Goutayer
Technología Ambiental S.A.
Pez Austral 9
28007 Madrid
Spain

Dr. José Iglesias
Instituto Esp. de Oceanografia
Centro Oceanografico de Vigo
Apdo 1552
36280 Vigo
Spain

Ms. Silvia Revenga
Secretaria General de Pesca Maritima,
Ortega y Gasset 57,
28006 Madrid,
Spain

SWEDEN

Dr. Per O. Larsson
Institute of Marine Research
P. O. Box 4
453 21 Lysekil
Sweden

UK

Dr. Julian Addison
Ministry of Agriculture, Fisheries & Food
Directorate of Fisheries Research
Fisheries Laboratory
Lowestoft, Suffolk, NR 33 0 HT
UK

Dr. R. Colin A. Bannister
Fisheries Laboratory
Lowestoft NR33 OHT
Suffolk
UK.

Prof. John H.S. Blaxter
Dunstaffnage Marine Research Laboratory
P.O.Box 3
Oban, Argyll,
PA34 4AD Scotland
UK

Mr. Craig A. Burton
Sea Fish Industry Authority
Marine Farming Unit
Ardtoe, Acharacle
Argyll, PH36 4LD
UK

Dr. Bari R. Howell
MAFF Fisheries Lab.
Benarth Road
Conwy, Gwynedd LL32 8UB
UK

Dr. Antony Jensen
Oceanography Department
Southampton University
Highfield
Southampton SO9 5NH.
UK.

Dr. Stephen J. Lockwood
MAFF Fisheries Lab.
Benarth Road
Conwy, Gwynedd LL32 8UB
UK

__Guests__

EUROPEAN COMMISSION

Dr. Willem J. Brugge
Commission of the European Communities
DG XIV (Fisheries)
Rue de la Loi 200
1049 Brussels
Belgium

Dr. Alain Laurec
Commission of the European Communities
DG XIV (Fisheries)
Rue de la Loi 200
1049 Brussels
Belgium

ITALY

Dr. Gianna Fabi
CNR, Instituto de Recerche
sulla Pesca Maritima
Molo Mandrachio
I-60100 Ancona
Italy

13.2 Working Documents

Not to be cited without prior reference to the authors

ICES Workshop to Evaluate the Potential for Stock Enhancement, 19-24 May, 1994, Charlottenlund Castle, Denmark

Lobster stock enhancement experiments

I. Historical perspective 1850-1980

J. T. Addison and R. C. A. Bannister

Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT England

Stocks of both the American (*Homarus americanus*) and the European (*Homarus gammarus*) lobster have supported substantial coastal trap fisheries for well over a century. Even before the turn of the century, some fisheries were changing substantially under the influence of exploitation, as in eastern Canada, where from 1880 to 1920 total landings of *H. americanus* declined progressively from 45 000 tonnes to 15 000 tonnes, before fluctuating round the 20 000 tonne level until the very recent upsurge to 45 000 tonnes once more (Elner and Campbell, 1991; Pezzack, 1992). In contrast landings of *H. gammarus* in Europe are at a much lower level fluctuating around 2 000 tonnes since 1950. Landings in parts of the English fishery certainly declined substantially in the 1950's (Bannister, 1986) while in Norway there has been a virtual disappearance of the stock (Tveite and Rørvik, 1982; van der Meeren *et al.*, 1990).

Against this background of declining fisheries, and with the high individual value of a lobster on the world market, the idea of lobster re-stocking has intuitive appeal. It seems to have attracted attention since the latter half of last century (e.g. de Maude, 1858; Ryder, 1886; Chadwick, 1904) when the idea of enhancement of natural stocks with hatchery-reared animals was part of a more far-sighted view of stock management when stocks were relatively under-exploited. This endeavour undoubtedly built on the formidable growth of knowledge in the morphology, physiology, and ecology of marine animals at the time, evidenced in the case of lobster by, for example, the work of Sars (1879) in Norway and Herrick (1909) in the USA.. The appeal of re-stocking comes from a widespread desire to compensate for the effects of exploitation by 'putting something back'. In particular, fishermen may hope to boost stocks and income without having to adopt restrictive management measures which limit their activities. On the other hand, ecologists familiar with the concept of density dependent mortality and stock-recruitment theory are likely to be somewhat sceptical.

REARING AND RELEASE OF LARVAE AND JUVENILES

The clawed lobsters *Homarus americanus* and *H. gammarus* have a relatively short larval period (approx. 4 weeks) and juvenile stages can be reared in the laboratory. The first reports of culture of larval *H. americanus* occurred in the 1870's (Anon., 1876;

Scattergood, 1949) and of *H. gammarus* in the 1860's (Moquin-Tandon and Soubeiran, 1865). By the early decades of this century successful hatcheries had been set up for *H. americanus* in the USA (e.g. Ryder, 1886; Barnes, 1906) and Canada (e.g. Wilmot, 1891; Delaney, 1912) and for *H. gammarus* in England (Chadwick 1904; Storrow, 1916), France (Roché, 1898) and Norway (Dannevig, 1928).

Much of the early work on lobster culture originated from an interest in the early life history stages, but the aim of setting up hatcheries was to rear large numbers of larvae or juveniles for release into the wild to augment natural stocks. There is no technical problem in rearing *Homarus spp.* to commercial size in a hatchery, but the development time from egg to mature adult is long. This long development time and the high rate of cannibalism in juvenile lobsters (Van Olst et al., 1975; Sastry and Zeitlin-Hale, 1977) makes culture to commercial size labour-intensive and therefore economically prohibitive (Beard *et al.*, 1985; Lee and Wickins, 1992), although development time can be shortened using heated power station effluent (Van Olst *et al.*, 1976). The impact of these early release experiments is not documented but it does not appear that landings increased significantly (Latrouite and Lorec, 1991), and by 1920 many of the earliest hatcheries had closed. However it is not always clear whether the closures occurred because of a perceived lack of success at enhancing the stocks, or because interest in the early life history stages of the lobster had by then been satisfied.

In the early and middle part of this century lobsters were reared to post-larvae (stage IV) in various hatcheries in the USA. Approximately 1 million post-larvae were released annually in Rhode Island, and an average of 200 000 annually in Maine (Thomas, 1964). Most of these hatcheries have now closed down, and we speculate that in practice most hatcheries closed because even with a moderate survival rate from post-larvae to commercial size, the economics of hatchery production were probably not sustainable given the high productivity of the natural fisheries for *H. americanus* on the eastern seaboard of North America. Since 1949 the most intense and sustained production of lobster larvae and juveniles has taken place at the Massachusetts State Lobster Hatchery and Research Station at Oak Bluffs on Martha's Vineyard, Mass., USA (Hughes *et al.*, 1972; 1974). In the first decade this hatchery reared and released a total of 1.5 million post-larval lobsters (Hughes and Matthiessen, 1962) and in recent years about 500 000 have been released every year (Syslo, 1986). Again the extent to which the hatchery-reared lobsters contributed to the natural population was not evaluated (Van Olst *et al.*, 1980). In France three hatcheries on the islands of Yeu, Houat and Sein in Brittany produced up to 250 000 stage V post-larvae (1st juvenile stage) and up to 15 000 one-year-old *H. gammarus* every year from 1972 to 1982 and released them onto the sea bed by divers (Henocque, 1983). Analysis of fishermen's log books, however, found no evidence of enhancement of the stocks (Le Gall *et al.*, 1983). Until methods of tagging of hatchery-reared animals were developed it was impossible to evaluate the biological success of such release programmes.

As an alternative to rearing and release of hatchery-reared lobsters, de Maude (1858) suggested creating sanctuaries where large berried (egg-bearing) female lobsters could be placed and protected. In France this activity was undertaken in the 1950's and 1960's prior to a switch to hatchery-rearing in the early 1970's (Latrouite and Lorec, 1991). Government agencies purchased berried females from fishermen, and in the sanctuary areas these females were protected and only males were selectively harvested.

Monitoring of the catch rate in these sanctuaries and in adjoining control areas showed that there was no evidence of long term enhancement of the sanctuary stock (D. Latrouite, pers. comm.).

TRANSPLANT OF ADULT LOBSTERS TO NEW GROUNDS AND INTRODUCTION OF LOBSTERS TO NEW GEOGRAPHICAL REGIONS

There have been numerous attempts at transplanting *H. americanus* to regions beyond the known geographical range of the species, in particular from the east to the west coast of North America (e.g. Smith, 1896; Butler, 1964; Ghelardi, 1967). Other attempts at establishing new fisheries include the introduction of *H. americanus* to Chesapeake Bay (Wood, 1885), of *Homarus gammarus* into New Zealand waters (Anderton, 1911; Thomson and Anderton, 1921) and of *Jasus lalandii* to France and Japan (Conan, 1986; Lee and Wickins, 1992). In many cases individual lobsters were reported captured some time after the introductions but in all cases there was no evidence of a sustained population. Most of these introductions were not rigorously monitored, although two notable examples of recent introductions describe post-introduction monitoring: release of juvenile *H. americanus* at the Koshiki Islands, Japan (Kittaka *et al.* 1983) and transplantation of *H. americanus* from Newfoundland to a southern Labrador site about 200 km to the north of the known geographical range (Boothroyd and Ennis, 1992). Monitoring of both experiments showed no established populations of *H. americanus* in the introduced area. On a local scale there have been numerous attempts to transplant *Homarus americanus* from a high density area of a fishery to try and boost stocks in another area, and indeed to this day some lobster fishermen in Europe illegally move pre-recruit lobsters (*H. gammarus*) to areas in which their own gear is situated, in order to enhance recruitment in their own area using juveniles from other fishing grounds.

IDENTIFICATION OF HATCHERY-REARED LOBSTERS

In most of the historical studies described above from the 19th and early 20th century no proof of enhancement of the stock was given, and it cannot be more than an assumption that hatchery-reared animals released into the wild survived and enhanced natural stocks. Dating from 1940 habitat limitation studies and the development of stock-recruitment theory encouraged scientists to question this basic assumption, and so in the 1960s and 1970s attempts were made to identify released animals in order to discriminate them from natural stock in the wild and thus evaluate the effect of release programmes. Where hatchery-reared animals are released outside their normal geographic range no marker is required, but in re-stocking programmes some biological markers were developed. Various colour-morphs were produced from controlled mating studies (Hughes, 1968), and progeny with genetic markers were obtained by mating adults with rare allozymes (Hedgecock, 1977). Both have potential to evaluate the success of release programmes but have not been used widely. Hybrids of *H. americanus* x *H. gammarus* were produced in hatcheries in France, USA and Japan (Carlberg *et al.*, 1978; J. T. Hughes, pers. comm.) whilst in France 1300 juvenile hybrids were released around Isle de Yeu (Latrouite and Lorec, 1991). There was no clear demonstration that F1 hybrids were caught however since electrophoretic analysis of enzymes did not clearly identify hybrids. One of the main morphological characters used for identifying hybrids, the presence of sub-rostral spines, is unlikely to be useful in UK waters where such spines have been found rarely but regularly in the natural populations of *H. gammarus* (MAFF, unpublished). Another method of identifying releases was discovered somewhat fortuitously when many hatchery programmes found that cultured lobsters tend to develop two symmetrical 'scissor' or 'cutter' claws instead of the normal asymmetrical scissor and crusher claw. This is because the crusher claw generally develops only when exercised (Govind, 1984; Govind and Pearce, 1992) and Wickins (1986) was able to stimulate crusher claw development in *H. gammarus* by adding oyster spat to the rearing chambers. In Norway a high proportion of lobsters caught close to some release areas had double scissor claws, thereby suggesting large scale survival of hatchery-reared lobsters in the wild (van der Meeren and Naess, 1993). However lobsters with two symmetrical scissor claws are again regularly observed in the wild in UK waters (MAFF, unpublished). These biological markers do not allow guaranteed identification of individual lobsters or even batches of lobsters and the methods were eventually superseded in the 1980s by the adoption of the coded microwire tag, which facilitates large scale testing of lobster catches for the presence of hatchery reared animals, providing data for estimating survival rates and hence quantitative evaluation of re-stocking programmes. We might conclude therefore that the lack of demonstrable success in historical re-stocking programmes appears to be due as much to the lack of a suitable tag for identifying hatchery-reared stock in the wild as to inherent biological factors.

RECENT PROGRESS

In the 1980's interest in lobster re-stocking was rekindled leading to a new wave of research in the United Kingdom, France, and later Norway and Ireland, most of which is still in progress. As described below, these studies involve new features which predispose them to be more successful than previous studies. Impetus for the new studies was particularly strong in the United Kingdom, where renewed concern about the depletion of lobster stocks coincided with further interest in lobster rearing, and with a greater perception about the relevance of lobster ecology. As an alternative to lobster rearing, which was technically feasible (Richards and Wickins, 1979) but economically unviable, it was proposed that a suitable application of the methodology could be the mass rearing of juveniles, followed by their direct placement on the sea bed on habitat favourable to lobster survival (Howard, 1988). This approach might by-pass the potentially high mortality presumed to occur in the larval phase (Figure 1). Juveniles would also be microtagged (Wickins *et al,* 1986) using techniques first developed for salmon (Jefferts *et al,* 1963), thus permitting detection of hatchery-reared stock during subsequent field sampling and monitoring of commercial landings. Controlled release on lobster habitat, the adoption of microtagging, and the development of a monitoring programme, represent three important innovations. Recognition of the role of habitat reflects the observation that commercial lobster fisheries occur predominantly in areas where a sea bed of rock or boulder provides shelter, and was supported by research showing that both juvenile and adult lobsters undertake adaptive behaviour to find and inhabit substrates which protect them from strong tidal flows and from predation (Cobb, 1971; Botero and Atema, 1982; Howard and Bennett, 1979; Howard and Nunny, 1983; Lawton, 1987).

Outside the UK, lobster stocking experiments have recently been reported in Norway (van der Meeren et al., 1990; 1993; this workshop), France (Latrouite and Lorec, 1991), Ireland (J. Mercer, pers. comm.) and in USA (B. Beal, pers. comm.). Experiments have now ceased in France but are continuing vigorously in the other countries.

Lobster stock enhancement experiments

II. Current experiments in the British Isles

C. A. Burton[1], R. C. A. Bannister[2], J. T. Addison[2] and W. Cook[3]

[1] Sea Fish Industry Authority, Marine Farming Unit, Ardtoe, Acharacle, Argyll PH36 4LD Scotland
[2] Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT England
[3] North Western and North Wales Sea Fisheries Committee, University of Lancaster, Bailrigg, Lancaster LA1 4XY England

INTRODUCTION

The present wave of lobster stock enhancement experiments in the British Isles originated in 1973 when the Ministry of Agriculture Fisheries and Food began research into the culture of the European lobster (*Homarus gammarus,* (L.)). At what is now the Fisheries Laboratory, Conwy, culture techniques were developed successfully (Richards and Wickins, 1979) but because economic prospects for intensive culture were poor, attention switched to an experiment to test the potential for enhancing wild lobster stocks depleted by fishing (Howard, 1982; 1988). As summarised in Part I, this experiment involved the development of a mass rearing and release programme for juvenile lobsters; the adoption of a technique for inserting a magnetised microwire tag into the base of a pereiopod so that each lobster could later be identified as being hatchery-reared; and the development of a recapture monitoring programme by the Fisheries Laboratory, Lowestoft. The MAFF enhancement experiment is sited at Bridlington on the English east coast, and commenced in 1983 (Bannister and Howard, 1991). Beginning in 1984, MAFF also shared technology in order to assist similar experiments set up by the Sea Fish Industry Authority (SFIA) at Loch Ceann Traigh, by Ardtoe in Argyll, and in Scapa Flow, Orkney (Burton, 1992), and by the North Western and North Wales Sea Fisheries Committee (NWNWSFC) at Aberystwyth (Povall et al., 1984; Cook et al., 1989). Later, in 1993, trials began in the Republic of Ireland, lobsters from the Shellfish Research Laboratory, Carna, being released in Smerwick Harbour, Co. Kerry, and in coastal waters in Co. Wexford (Mercer, *pers. comm.*). Figure 2 shows the location of these various sites. The Bridlington, Scapa, Aberystwyth, Smerwick and Wexford areas support significant natural lobster fisheries, whilst at Ardtoe small numbers of lobsters are caught as a by-catch in the local velvet crab fishery. The experimental sites therefore all contain habitat suitable for the survival of lobsters, ranging from fissured bedrock, to underwater scree slopes, to reefs of large boulder or smaller cobble scattered over sand and or muddy moraine.

METHODS

In the UK experiments, hatchery-reared juvenile lobsters were grown from wild egg-bearing broodstock using techniques described in full in Beard et al. (1985), Beard and Wickins (1992), Burton (1992), and Povall et al. (1984). The microtagging technique used the binary-coded Bergman-Jefferts internal tag adapted for use in the lobster, as described by Wickins et al. (1986). Tag retention was shown to be good (Wickins et al., 1986). Lobsters were generally reared for three months to reach stage XII, at about 15 mm carapace length, before being transported to the release area in recirculating systems. From 1983 to 1988 lobsters were released underwater onto known areas of lobster habitat, mainly in the summer period between June and September, but occasionally as late as November. Lobsters were mostly tipped onto the sea-bed at precise locations from compartmentalised trays carried down by divers (MAFF, SFIA), but at Aberystwyth, and on a few occasions at Bridlington, lobsters were scattered more widely from an underwater pipe manipulated by divers operating from a drifting boat (Povall, Cook and Oxford, 1984). In the SFIA releases, lobsters were usually acclimated on the sea-bed for a short period before being released.

Initial recapture surveys began at Ardtoe using divers, and the first confirmed recaptures of hatchery-reared juveniles were made by diver at this site (Walker, 1986). Subsequent recapture monitoring by the three experimental groups has mainly involved target fishing using traps set at precisely known locations, plus large-scale sampling of lobster landings at the main ports for each fishery. Lobsters caught or landed in this way were individually tested for the presence of a microtag using a tubular magnetometer set up on the quayside, or at lobster holding facilities, and the tag subsequently dissected out and decoded after returning the lobster to the laboratory. In these experiments the binary code was specific for the year of release, but not for each individual animal.

RELEASE AND RECAPTURE SUMMARY

For the three UK experimental groups (i.e. excluding the newly commenced Irish trials), Tables I, II and III summarise the number of lobsters released between 1983 and 1988, and recaptured from 1985 to 1993. Release totals have been corrected for tag loss. The total number of lobsters released is a substantial 93000, but this comprises many batches released at a range of individual sites in different years. At Bridlington the release total of 49 128 lobsters comprised eighty individual batches of 200 to 2000 animals distributed throughout the inner four mile band of the fishery. At Ardtoe, 3044 lobsters were released at fourteen individual locations round the edge of Loch Ceann Traigh, and at Scapa Flow 19 520 lobsters were released at thirty two individual locations round the edge of the Flow and its islands. In the NWNWSFC experiment lobsters were released in only two main areas, however, one close inshore along the coast south of Aberystwyth, and a second separate area comprising three adjacent grounds four miles offshore (the Outer Patch).

To date, recaptures from all groups total 1457 lobsters, allocated by year of release and recapture as shown in part A of Tables I to III. As a proportion of the number released, the gross recapture rate varies form 0.5% to 5.5% depending on the site and the year of release, the overall average being 1.6%. These figures are only a very coarse summary of the results, but they illustrate that a substantial number of hatchery-reared lobsters has survived up to eight years after release, and that they can be caught in commercial lobster traps. The tables combine recaptures from diving, target fishing and quayside sampling, and the recapture rate varies between years and experimental groups depending on the amount and allocation of the sampling effort, and according to the nature of the fishery. The Scapa and Bridlington fisheries cover extensive areas, of which the release sites represent only a small proportion, so a fisherman is less likely to encounter a tagged lobster there than at, say, the Outer Patch off Aberystwyth, where the release sites and the fishery are more concentrated. It is not possible to adjust the basic recapture data for the proportion of samples originating from locations where lobsters were not released, but for the MAFF data a more detailed evaluation of the recapture rate based on another approach is summarised in part III, leading to preliminary estimates of abundance and survival.

Part B of the tables shows the size range of recaptures for each release and recapture year. This illustrates lobster growth, although it is also affected by sampling bias, since, up to 1990, the data include sub-legal animals recaptured by target fishing, whereas since 1990 the number of sub-legal animals tested for microtags has declined substantially for operational reasons, and results are biased towards the legal size range. The data illustrate a wide variation of size at age, and show that individuals released at approximately the same size have pursued different growth trajectories both within and between cohorts. The pattern of growth between areas is broadly similar, however. Thus at Bridlington the 1983 cohort reached legal size in six years, but later cohorts reached legal size after five or even four years. At Ardtoe and Scapa Flow most recaptures reached legal size in five years. At Aberystwyth, most cohorts reached legal size four to six years after release. (Lobsters of the 1988 cohort reached legal size after only three years, but these lobsters had been released at the unusually large size of 20 mm CL.) All three experimental groups have recaptured mature females carrying eggs, showing that some hatchery-reared lobsters had matured, mated and were potentially capable of contributing to population egg production. For more detailed results see Bannister et al. (1991, 1994) and Burton (1993).

Because of the importance of accurate growth data for fisheries assessments, hatchery-reared recaptures of known age are currently being used to test whether the brain pigment lipofuscin accumulates in proportion to chronological age. This work is still in progress (Wickins and Sheehy, 1993)

EARLY RELEASE TRIALS

From 1989 to 1992 the SFIA released 10 861 stage VI to VIII juveniles on sites at Ardtoe, to test the scope for using smaller, and therefore cheaper, lobsters in enhancement programmes. These lobsters contained a half size microtag. So far, two 1989 animals were caught in 1993 at 65 mm CL, rather on the small side, suggesting that these lobsters may take longer than normal to reach market size. Recapture monitoring is ongoing.

SITE FIDELITY AND EMIGRATION.

Recaptures from target fishing operations provide accurate positional data. These show that in all experiments, many recaptures were clustered in the vicinity of known release sites, mostly within a distance of 5 km., although at Ardtoe, Scapa and Aberystwyth, a small number of individuals were also recaptured at distances beyond this. At Bridlington, there is no evidence that hatchery-reared lobsters have emigrated from the release area, since no hatchery-reared animals have been found in the large number of lobsters caught commercially several miles to seaward of the release sites. At Aberystwyth, on the other hand, lobsters released inshore were in some cases later recaptured at the Outer Patch, suggesting that some lobsters recruit to the offshore grounds in this area. In general, however, the experimental results favour the conclusion that lobsters placed on suitable habitat tend to stay in its vicinity, at least for the first eight or nine years of life, and that the proportion of animals likely to emigrate from such a release area is low.

CONCLUSIONS

These results provide the first clear cut evidence that hatchery-reared juvenile lobsters released onto suitable habitat in the wild, survive in substantial numbers to be captured in baited traps by commercial fishermen, and mature to the egg carrying stage. Such lobsters take four to six years to reach legal size, and they generally remain close to where they were released, or recruit to local lobster grounds nearby.

Lobster stock enhancement experiments

III. Estimating survival and assessing future fishery applications

R. C. A. Bannister, J. T. Addison and S. R. J. Lovewell

Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT England

INTRODUCTION

Most lobster stocks are heavily fished, so that stocks of legal sized lobsters are depleted. The fundamental aim of the present UK lobster stock enhancement experiments has been to investigate whether hatchery-reared juveniles could restock such populations. As shown in part II, initial results appear to be biologically successful. The experimental groups have reared large numbers of juvenile European lobsters in the laboratory, released them onto commercial fishing grounds, and recaptured 1460 animals including females that had matured and were carrying eggs. Although it is appears to be feasible to enhance natural stocks through the release of hatchery-reared juveniles, some questions remain to be answered before lobster stocking programmes become a commercial reality. Firstly can we estimate the actual survival rate of hatchery-reared lobsters, secondly? do hatchery-reared lobsters augment or displace natural lobster stocks, and thirdly can we interpret the recapture rate in relation to production costs, and to strategies for restocking or developing lobster fisheries?

ESTIMATING THE ABUNDANCE AND SURVIVAL RATE OF HATCHERY-REARED LOBSTERS

The MAFF recapture total at Bridlington is substantial in comparison to similar recent experiments in France (Latrouite and Lorec, 1991) and this section of the paper investigates if our recapture data can be used to quantify the survival of hatchery-reared juveniles through to recruitment to the fishery. In the Bridlington fishery, these recaptures represent only 1-2% of the number of lobsters released and also only about 1% of lobsters tested at the landing place (Table I, and see Bannister et al., 1994). At first sight there appears therefore to be only a low survival of released lobsters and little contribution of hatchery-reared lobsters to the overall landings. These recapture rates are an underestimate, as only a proportion of all lobsters landed from the fishing area could be tested for the presence of microtags. There is no doubt that with greater sampling resources the gross number of recaptures would have been much higher. Also, as noted in part II, the microtag recapture rate is diluted by sampling many landings at Bridlington from vessels fishing outside the immediate release area, and which yielded no recaptures, (although showing at the same time that there was no offshore dispersal of hatchery-reared stock). A more realistic way of evaluating the results is to use data from the field sampling part of the monitoring programme in known release areas, and to attempt to estimate the underlying abundance of the surviving hatchery-reared stock in the vicinity of those known release sites. From 1989 to 1992, the catch per effort of microtagged lobsters in field sampling hauls yielding recaptures was 6 lobsters per 100 pot hauls, compared to total catch rates of 40-85 lobsters per 100 pot hauls using the same gear.

This suggests that at individual release sites hatchery-reared stock comprised 7-16% of the lobsters available for capture, representing a significant proportion of the catch.

Methods for estimating survival of cohorts of hatchery-reared animals

From the release and recapture programmes we know the absolute number of microtagged lobsters released in each batch at individual release sites, and the catch rate of microtagged lobsters for strings of pots fished at various field sampling locations, some close to release sites. We have developed a method for converting the catch per effort of microtagged lobsters in field sampling hauls to an estimate of their abundance, which can in turn be used to estimate the survival rate from the time of release to the time of recapture.

From the catch equation (Ricker, 1958), the catch of microtagged lobsters during any single field sampling occasion will be

$$C'_m = N'_m \cdot u \quad \text{..................Equation 1,}$$

where C'_m is the number of microtagged lobsters caught, N'_m is the abundance of microtagged lobsters on the ground, and $u = F'(1\text{-}e^{-Z'}) / Z'$, a combined term defining the exploitation rate based on F' and Z', respectively the instantaneous fishing and total mortality rates per day. (The prime symbol signifies terms generated daily by one haul of a standard string of pots at the field sampling location, rather than the more usual annual rate). We can therefore estimate N'_m from observations of C'_m, using an estimate of u for standard hauls by the field sampling vessel.

We estimated u from a supplementary external tag-recapture experiment carried out in a clearly-delineated patch of ground in the lobster release area in 1990. The field sampling vessel set 150 pots to cover this entire small area throughout the fishing season, and hauled them daily for a week during periodic visits. (At other times the pots were left to claim the ground and exclude other fishermen.) Undersized lobsters were tagged using individually numbered plastic T-bar tags (Hallprint Pty Ltd., Australia), then returned to the sea over the same ground. Tagged lobsters caught again during the experiment were recorded and returned to the sea, including any lobsters which had moulted to legal size. It is assumed therefore that during the season there was no depletion of tagged lobsters due to fishing.

For this conventional tagging experiment we assume that the recapture of T-bar tagged lobsters each day is also a function of the catch equation

$$C'_t = N'_t \cdot u \quad \text{................Equation 2}$$

where C'_t is the number of T-bar tag recaptures each day, N'_t is the tagged population (cumulative number of tagged lobsters released), and $u = F'(1\text{-}e^{-Z'}) / Z'$, the exploitation rate based on F' and Z' (in this case the instantaneous fishing and total mortality rates generated by 150 pot lifts per day in 1990). As the experimental fishing effort in each area is constant each day, daily recaptures should be a constant proportion of the known tagged population through time, so that we can estimate u as the slope of the linear relationship between recaptures per day C'_t, and the cumulative number of tagged lobsters, N'_t. (This is analogous to the method of Schumacher and Eschmeyer as described in Krebs (1989)).

This approach to estimating u assumes that tagged and untagged lobsters are well-mixed, and that the tagged population is not affected by tagging mortality, tag loss, dispersion, or immigration. Mixing was achieved by returning tagged lobsters to the sea when the experimental pots were hauled and shot over the same ground in a small area. Tagging mortality and tag loss could not be measured in this experiment, but in order to investigate their possible effect the exploitation rate was first calculated assuming no tagging mortality and no tag loss. We then simulated a likely worst case in which the number of lobsters tagged on each sampling occasion was reduced by an assumed 20% instantaneous tagging mortality, whilst the resulting cumulative tagged population was discounted by a steady daily instantaneous mortality rate (accumulating to a 12% tag loss per month) representing a combination of tag shedding, dispersion, or dilution due to immigration. As our results suggested little local movement out of the tagging area, this factor will represent mainly tag shedding.

Results of the T-bar tag-recapture experiment.

Beginning in early April 1990, 150 pots were hauled on 31 individual days and 291 sub-legal lobsters were tagged. Recaptures began when the tagged population exceeded 100 animals in mid-May in 1990, reached a peak by mid-August (day 232), and continued to mid-September. After day 257 recaptures declined suddenly suggesting an end of season decrease in catchability. In Figure 3 the observed number of T-bar tag recaptures per day for 1990 is regressed against cumulative tag number, without adjusting for tagging mortality or tag loss, but omitting the last two data points affected by the presumed end of season change in catchability. The slope of 0.0171, representing the exploitation rate $F'(1-e^{-Z'})/Z'$ per 150 pot hauls, is highly significant ($F = 64.8$; $P < 0.0001$). The experiment was repeated in a different site within the release area in 1991 using 100 pots only (see Bannister et al. (1994) for further details). Recaptures from 816 tagged undersized lobsters were used to estimate the slope of $F'(1-e^{-Z'})/Z'$ per 100 pots as 0.0125 ($F = 24.9$; $P < 0.0001$). The estimated slopes for 1990 and 1991 are in roughly the same proportion as the number of pots deployed in the two areas, suggesting that the experimental gear generated a similar exploitation rate on lobsters in two different years independently of the location and size of the tagged population. This result makes no allowance for any violation of assumptions. For the worst case scenario involving tag losses described above, however, the exploitation rate per 150 pots in 1990 increases to 0.0282 ($F = 52.7$; $P < 0.0001$).

Abundance and survival estimation

During field sampling, 214 microtagged lobsters were caught in single strings of 25 to 30 pots, usually at the rate of one or two animals a string, but occasionally comprising up to eight microtagged lobsters a string. For each release cohort and recapture year, these data were assigned to the nearest release site for that cohort, averaged if there was more than one sample, then multiplied up to the catch which would have been taken by 150 pot hauls. This gives the equivalent microtagged catch per 150 pot hauls. Following equation 1, raised catches were converted to best and worst abundance estimates using the exploitation rates 0.0171 and 0.0282 calculated previously for 1990. These abundances can be compared with the number of hatchery-reared lobsters originally released at each site, and hence an estimate of survival made.

Results comprise forty eight spot estimates of abundance, cohorts 1984 and 1985 being well sampled, but the remainder less so. Comparing these estimates against the number of lobsters released at each site gives survival estimates whose grand mean across all cohorts and years is 0.79 and 0.47 for the best and worst assumptions about tag mortality etc.. The data have a high variance but suggest that even allowing for errors in the tag-recapture approach, plus uncertainties involved in assigning recapture data to release batches, there has nonetheless been a substantial survival of juvenile lobsters from release to recruitment four to eight years later. Local recapture rates of one or two lobsters per string of 30 pots hauled therefore appear to correspond to a substantial number of microtagged lobsters on the ground. This is gratifying, for despite the large size of the fishery as a whole, the numbers of lobsters released in the eighty individual release batches were quite small, ranging from 200 to 2000, and were distributed at widely scattered sites. This will have reduced the probability of recapture, and also contributed substantially to field sampling variability the statistical properties of which we have not yet been able to examine in detail. Recaptures might have been more dramatic had lobsters been released every year onto the same area of habitat, or, as with the recent experiments in Norway, onto habitat with little or no natural lobster stock.

Whilst the underlying assumptions about tagging mortality, tag shedding, and immigration, as well as local and seasonal sampling attributes, need further examination to test the robustness of our estimates, these preliminary results appear to be of considerable importance for both life history and enhancement studies. From the life history viewpoint, our results could be the first to point to the good pre-recruit survival which we consider to be consistent with juvenile shelter seeking behaviour (Cobb, 1971), and with low adult fecundity in this species. Our results may also suggest that habitat has not been limiting to the juvenile phase in this area. From the enhancement viewpoint, the possibility that pre-recruit survival is good means that hatchery-reared lobsters may at the very least be able to enhance egg production substantially, whilst the high proportion of microtagged lobsters in some field sampling hauls is also encouraging from the fishery viewpoint.

DO HATCHERY-REARED LOBSTERS AUGMENT OR DISPLACE NATURAL LOBSTER STOCKS?

Evaluating whether hatchery-reared juveniles released onto the sea bed have actually enhanced the fishery presents a series of problems. Major experimental manipulations such as this cannot be treated as true ecological experiments. Firstly, although UK groups have repeated the experiment in four geographical areas with differing geological nature, we were unable to set up replicate experiments with suitable controls within each experimental area. Secondly, we have only limited knowledge about initial conditions prior to the release of the hatchery-reared lobsters. Thirdly, filtering out the influence of natural fluctuations in stock abundance is also difficult. We thus do not have sufficient information to fully evaluate the impact of the release programme. However this is similar to the introduction of conventional fisheries management regulations, which are rarely carefully controlled ecological experiments, in which long term benefits have been clearly demonstrated. For example, we are not aware of any increase in minimum landing size in a lobster fishery which has been shown unequivocally to have increased landings or stock size.

The previous sections outlined methods we have used to estimate a survival rate of 50-80% for individual cohorts of released juveniles. However we have not been able to determine whether these juveniles have survived in addition to the natural stock of juveniles or whether they have simply displaced natural stock from their refuges. The UK experiments were not originally designed to answer this question, but recent stocking experiments in Norway (described by G. Van der Meeren at this workshop) will hope to address this problem specifically. At present we can only speculate about the likelihood of hatchery-reared juveniles displacing as opposed to enhancing the natural stock based on what is known about regulation in lobster populations. At what life history stage do we expect that density dependent mortality is most likely to occur? Are lobster populations limited by habitat availability? These issues have recently been reviewed by Addison and Fogarty (1992). The only clear evidence that some form of compensatory mortality occurs within the life-cycle of the lobster comes from a re-analysis of Scarratt's (1973) data by Fogarty and Idoine (1986). The data suggested that the compensatory response may occur early during the period between the fourth larval stage and recruitment to the fishery, i.e. in the juvenile stages. It is not clear what form the regulatory mechanism takes but habitat limitation is a reasonable hypothesis which has been taken up by some authors. Wahle and Steneck's (1991) studies in the Gulf of Maine suggested that habitat might be limiting in early benthic phase lobsters, but this has been countered by both Miller et al. (1991) and P. Lawton (DFO, St. Andrews, Canada, pers. comm.) who used diver surveys to conclude that habitat is not limiting for juveniles in Nova Scotia and New Brunswick respectively. Some elegant experiments recently reported by Rick Wahle of University of Rhode Island, USA (International Lobster Workshop, Galway, Ireland, April 1994) demonstrated that in some areas habitat appears to be limiting at very high densities of juvenile lobsters. However Wahle also presented clear evidence that in some areas where suitable lobster habitat appeared to be abundant, there was limited recruitment due to weak larval transport in the area.

For our own study area in Bridlington, we have found good correlations between pre-recruit lobster catch rates and recruitment in the following year (Addison et al., in press). The abundance of pre-recruit lobsters is as high in this fishery as any area in England and varied considerably from year to year. As pre-recruit catch rates provided a good predictor of recruit catch rates in the following year we can assume that even at these high densities, it seems unlikely that habitat is limiting for lobsters of pre-recruit size. Considering that fishing in the inshore part of Bridlington Bay normally removes at least 30 000 lobsters a year, but the total number of hatchery reared animals added in any of the release years did not exceed 15 000, we could argue that natural animals were unlikely to be displaced, at least at the larger sizes. Further, although we have no field data on competition for habitat in the juvenile stages, our hatchery-reared lobsters were released in quite small batches at many individual locations in Bridlington Bay, and this must have reduced the likelihood of death from competition. Finally, the lack of dispersion in the recaptures might indicate that lobsters were not forced out of the release areas in order to survive. Although a new and complex experiment would be required to investigate the problem of carrying capacity scientifically, there is therefore some circumstantial evidence from the existing results in favour of augmentation. Currently, therefore we have no evidence that, at the depleted stock densities at which we might consider a stocking programme, hatchery-reared lobsters would be likely to displace natural stock due to a lack of habitat, provided the latter is recognisably typical of what lobsters require.

STOCKING AND RECAPTURE CALCULATIONS

It is important to consider what a commercial stock enhancement programme might involve, as exemplified by the following example. A typical local lobster fishery in the UK involves 10 to 20 fishermen working from small boats of 8 to 12 metres in length, each hauling from 10 to 30 strings of pots, each string comprising 25 to 30 pots. A fishery of this type probably lands 10 to 30 tonnes of lobsters a year, equivalent to 20 000 to 60 000 lobsters weighing approximately 1 lb. each. A typical lobsterman might fish for 7 months of the year, and haul on say 21 days each month, that is approximately 150 days a year. Averaged over the year a lobsterman in a depleted fishery may land 30 lb. of lobsters a day, or 4 500 lobsters per annum, equivalent to 45 000 lobsters for a ten man fishery.

With our present knowledge it is difficult to say how many lobsters we would have to stock to create a fishery of this scale. We already know that the gross recapture rate of 1% is almost certainly a considerable underestimate of the likely true recapture rate, which is just as well, since it would otherwise imply that a stock of 4.5 million lobsters would be needed to support a 45 000 lobster per annum fishery. As before, it is more realistic to look at the average CPUE of hatchery-reared lobsters in the Bridlington Bay experiment, 6 lobsters per 100 pot hauls. At this catch rate, an annual catch of 45 000 lobsters requires 750 000 pot hauls. One fisherman with 500 traps hauled on 150 days a year generates 75 000 pot hauls, suggesting that the target catch could be obtained by 10 fishermen of this type, fishing lobsters at the same density and capture efficiency as in our experiment. This is encouraging, but it is not clear if the underlying catch rate will be profitable in its own right. We may need to stock larger numbers at a higher density than was done in the experiments, if the fishery is to be profitable in its own right.

A colleague has undertaken a preliminary financial appraisal of a lobster enhancement scheme, based on a small-scale hatchery design within the likely budget of a small group. Under the constraints that the initial building and hardware costs, excluding site purchase, should not exceed £100 000, and that the annual rearing programme could be carried out by two men at a cost not exceeding £50 000 per annum, experience at Conwy (J Wickins, personal communication) leads to a hatchery design producing 30 000 juvenile lobsters a year at £1.50 each. Since it takes five years for lobsters to reach legal size, and assuming that we can expect at least 50 % survival, the minimum fishable stock after the first 5 years will only be 15 000 lobsters. It will require another four years to establish something approaching the full fishable size range, corresponding to a stock of approximately 50 000 lobsters, and the programme will need to be continued for a very substantial period in order to recoup costs. In fact, assuming a production cost of £1.50 per lobster, an average market price of £4.50 per legal sized lobster, a public sector project discount rate of 5%, and assuming no additional costs of fishing, (i.e. the fishery is already in being) calculations suggests that we could require to run for 25 years, and to recapture 20-30% of the stock overall, in order to break even (D. Whitmarsh, pers. comm.). The level of stocking in this example will probably only support a five man fishery, and we would require a much larger scale if a big fishery were to be contemplated. A lobster enhancement programme is clearly a substantial long term undertaking, and quick results cannot be expected. Production costs, market price, stocking rate and recapture rate, are obviously all very critical to the outcome. Finally for any proposed commercial stocking programme, the problem of ownership of the introduced stock needs to be resolved.

CONCLUSIONS

The present UK experiments are the first to obtain clear-cut evidence that substantial numbers of hatchery-reared juvenile lobsters may survive in the wild to reach commercial size and be caught by fishermen (Addison and Bannister, 1994). They are also the first to permit an estimate of lobster survival between the juvenile stage and legal size, and to show that surviving females have produced eggs. Biologically, therefore, the experiments and their methods have been successful, and we are now considering the potential application of these results to the real world. The preliminary fishery and economic calculations presented in the last section, though speculative, give some guidance about the likely scale and duration required to establish a realistic lobster enhancement programme for a typical coastal fishery. At this stage it is difficult to determine whether such a programme could break even financially or whether it will inevitably require subsidy from other commercial ventures, or from the public purse. Profitability is very sensitive to production costs, market price, and the scale of the stocking programme, and the present indications are that schemes will require to recapture at least 20-30% of the stock over a 25-30 year period, a fairly demanding profile. We feel that the next step must be a real world trial in a suitable small-scale fishery area with low natural catch rates, where we can evaluate the economics more fully.

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Some Considerations About Annual Growth Rate Variations In Cod and Flatfish Stocks.

by

Enrique de Cárdenas

Instituto Esp. de Oceanografía P.O.Box 240
Santander Spain.

Abstract

In the present paper the annual evolution in the mean weight at age in the stock is studied for 3 populations of cod (Northeast Arctic cod stock, Icelandic cod stock, and 2J3KL NAFO Divisions cod stock) and 3 populations of flat fish (English Channel plaice, Irish Sea plaice and English Channel sole).

In the six populations analysed, a strong annual effect is appreciated since all ages of the same stock seem to have the same trends each year. This is particularly apparent in the two stocks of flat fish in the English Channel.

In the three cod stocks analysed, the behaviour of ages 3-7 is very similar, though older ages differ somewhat more.

In most cases, the annual increases seem to have little relationship with the stock biomass. Nevertheless, except in the case of sole, the maximums of biomass usually bring about falls in growth rates. The plaice stocks are the only ones in which a relationship between growth rate and stock biomass can be slightly appreciated.

In the case of the cod stocks growth rate appears to be related to both temperature and availability of capelin (capelin biomass/cod biomass ratio).

Introduction

Growth rates suffer great variations according to the environment. Some of the most important factors affecting growth are availability of food (which provides energy) and temperature (which accelerates the metabolism).

Wooton (1990) carried out a revision of factors affecting teleost fish growth from studies done in both natural environments and laboratory. He summarises, among others, the following conclusions: "Growth depends on energy and nutrients provided in food, the relationship between growth rate and ration size at the same temperature is usually curvilinear approaching an asymptote at high rations." and "At maximum rations growth rate increases with increase in temperature up to a peak but then decreases with further increase in temperature. At low rations growth rate declines with increasing temperature."

Temperature could have two effects on fish growth, one direct, as it regulates the rate of fish metabolism, and another indirect acting on the growth of prey, and that of the prey of prey, affecting the biomass of prey available to the predator.

A possible relationship between fish growth and density has been suggested, for example, Lett and Doubleday (1976) suggest that this relationship would constitute a mechanism which regulates the population of Gulf of Saint Lawrence cod. Where an increase in density of cod will bring about a fall in the quantity of food per predator, consequently increasing the time spent in the search for food and the period of time between feeding, which will affect the quantity of energy brought, and, as we have seen (Wooton, 1990), the growth and fecundity of cod will decrease. Pérez-Gándaras and Zamarro (1990) also suggested that growth was density dependent at the time of Flemish Cap cod recruitment. A good relationship between the density and the fall in the quantity of food can be only expect when the quantity of food available at the beginning of the year is constant. Nevertheless, the quantity of food available (prey biomass), does not only fail to remain constant, but tends to vary even more than predator biomass, given that, as these organisms come earlier in the food chain, they are usually more opportunist than their predators and will consequently fluctuate more according to fluctuations in the environment.

For this reason, authors like Joergensen (1992), search for a more accurately index of food availability, and successfully test the relationship between growth and the capelin biomass fraction (the main prey of cod) divided by total cod biomass.

The aim of the present study is to analyse the behaviour of the increases in the average weight by age for the different age groups to see whether they follow similar trends, and to try to relate these trends to the stock biomass, to an index of availability of prey and to an index of temperature.

Material and Methods

For the present study, data of average weight by age in the stocks corresponding to three cod populations (Northeast Arctic cod, Icelandic cod and NAFO Divisions 2J3KL cod), and three of flat fish (English Channel sole and plaice and Irish Sea plaice) has been used.

The data comes from ICES Working Group reports (Anon. 1993a; 1993b; 1994;) and Bishop et al. (1993).

For each of the stocks studied, weight increases were calculated for each year and age

$$\Delta W_{ya} = W_{y+1\ a+1} - W_{ya}$$

where

ΔW_{ya} = Weight increase undergone by the age group a throughout the year y.

$W_{y+1\ a+1}$ = Average weight of the age a+1 in the year y+1.

W_{ya} = Average weight of the age a in the year y.

For each of the ages the average for the period studied was obtained using the formula:

$$\Delta \overline{W}_y = \Sigma \Delta W_y / N$$

The differences of each year with respect to the average were obtained as follows:

$$\text{dif } W_y = \Delta W_y - \Delta \overline{W}_y$$

The standard deviation of these was extracted and used to normalise each of the series, dividing them by their standard deviation.

This permits the representation of the behaviour of each age in the same units.

The normalised series are represented together to observe whether similar trends exist in the growth evolution of different ages, and separated to check that ages behave in similar ways.

To analyse whether a relationship exists between annual increases and population density, the total stock biomass was used as an index of its density.

The series of total stock biomass was normalised to be analogous to the series of growth rate by age.

As the expected relationship between growth and density is negative, the series of normalised total biomass was multiplied by -1 to represent this factor more clearly, and is shown together with the series of growth rates of ages 3 to 7.

Icelandic cod growth rates were compared with the series of normalised capelin biomass/cod biomass, which is a index of availability of the main prey of cod.

Finally, the growth rates of cod from NAFO Divisions 2J3KL were compared with the normalised series of the CIL area (Cold Intermediate Layer) of Bonavista (Sinclair, 1992), with the sign changed, which can be considered as an index of winter coldness.

Results

In each of the 6 populations studied, similar trends are detected in the behaviour of all ages (Figs. 1-6). This phenomenon is particularly clear in the two flat fish stocks of the English Channel (Figs. 5 and 6). Nevertheless, the factor controlling the growth rates of these two populations seems to be different, since the trends of the two populations do not coincide (Fig. 7).

In each of the cod stocks studied, a great similarity exists in growth behaviour of the series of age groups less than 7 years (Figs. 1, 2, 3; below).

Comparing the annual growth with biomass with the sign changed it can be seen that in the case of Arctic cod there is a one year delay in the growth response to changes in biomass, although this relationship disappears in the last two years (Fig. 8). Nevertheless, in the case of Icelandic cod the response seems to come in the same year. Nor does there seem to be a great relationship if the period 1980-88 is excluded (Fig. 9 above). Lastly, in cod from NAFO Divisions 2J3KL, the growth rate change even seems to come forward a year, with which the relationship between these two parameters is not clear either (Fig. 10 above).

With respect to the flat fish stocks, no relationship seems to exist between the biomass evolution of sole and growth rate changes (Fig. 12). Nevertheless, in the plaice stocks a somewhat greater relationship may exist (Fig. 11 above and below).

When growth rates of cod are analysed as a function of the index of available prey in the case of Icelandic cod, a much better fit is obtained than when the stock biomass is used, although age 3 tends to deviate from the general tendency with respect to the biomass with the sign changed (Fig. 9 above and below).

Finally, examining cod growth rates in NAFO Divisions 2J3KL with respect to the coldness index in the area (area of the Cold Intermediate Layer multiplied by -1) a much better fit is observed in the evolution of this variable with respect to the growth rates than those seen considering the stock biomass with the sign changed (Fig. 10 above and below).

Discussion

It is not surprising that the trends in weight growth of different ages are similar, since the determining factors of growth each year, which, as we have seen in the introduction are mainly availability of food and temperature, tend to affect the whole population. However, their different relative importance in some age groups than in others may bring about greater similarity in ages below 7 years in cod, particularly when we take into account that cod reach maturity at around 6-7 years, with the physiological and behavioural changes that come with it (remember migrations).

None of the stocks observed seem to present a good correlation between growth rates and total stock biomass.

This would seem surprising, at first, since a relationship between predator density and diminishing availability of food was expected, and this lesser availability of food would bring with it a fall in weight growth. The lack of a clear relationship between stock biomass and growth rates is due, among other reasons, to two factors: 1) An increase in the biomass of the population is not always strictly manifested as an increase in density, since it can bring about an increase in the area of distribution. This phenomenon is well known in pelagic fish of short lifespan such as the anchovy or sardine (Mac Call, 1990, but also appears in demersal species like cod (Swain and Wade, 1993). 2) Prey density will also constitute a regulating factor of the availability of food and while the prey/predator ratio remains constant, growth should not be affected by the availability of food as long as the overlapping of the distribution of predator and prey remains constant. In fact, when we analyse the evolution of an index of food availability, such as the capelin stock biomass/cod stock biomass ratio in the case of Icelandic cod, we find a better fit with the weight increments. Magnusson and Palsson (1991) explain this relationship "cod can only partially compensate for the loss of capelin by switching to other food. This holds true for all age groups of cod between 3 and 8 years old". The greater difference found at age 3 could be due to the fact that at this age capelin still makes up a small percentage of diet as can be seen, for example, in Garasimova et al. (1992). Magnusson and Palsson (1991) also suggest that capelin have greater importance in cod diet at age 5-7 years than at 3 years. The same authors provide another interesting piece of information in that "The results indicate that cod growth, biomass and yields, are not greatly affected as long as capelin biomass is above approximately 2 million tonnes. When capelin biomass is further reduced a more rapid decline in growth , biomass and yield is observed". This capelin/cod index was also used successfully in Norwegian Arctic cod (Joergersen, 1992).

With respect to increases in growth rates due to physical factors, we also find a relationship between growth increases and the area of the CIL at Bonavista, for Divisions 2J3KL cod. CIL area can be used to estimated the variability in the oceanographic conditions on the continental shelf off Newfoundland and southern Labrador (Narayanan *et al.*, 1992). So a greater area of the CIL, could indicate that the year is colder, with the double effect mentioned in the introduction that this may have on fish growth, but it could also be acting on its concentration, since cod does not penetrate the area of the CIL (Hardy, 1978) and so as the area of the CIL increases the area available to cod is consequently reduced, and it is obliged to concentrate at the bottom or over the slope.

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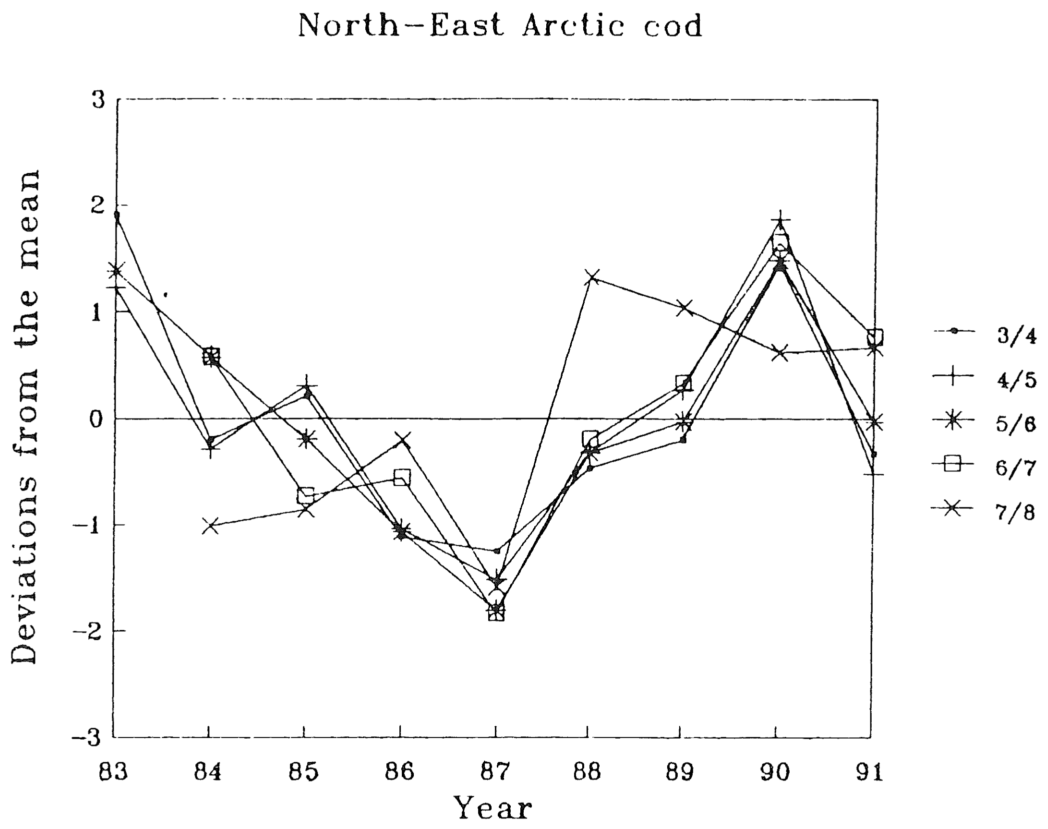


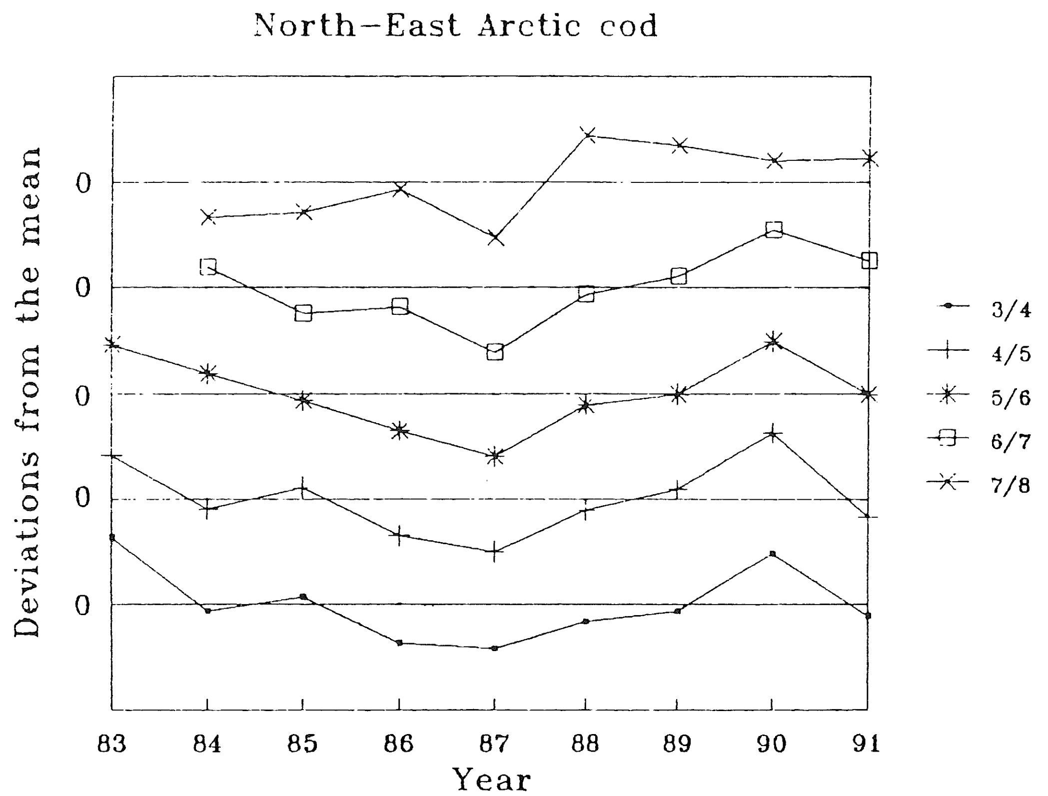
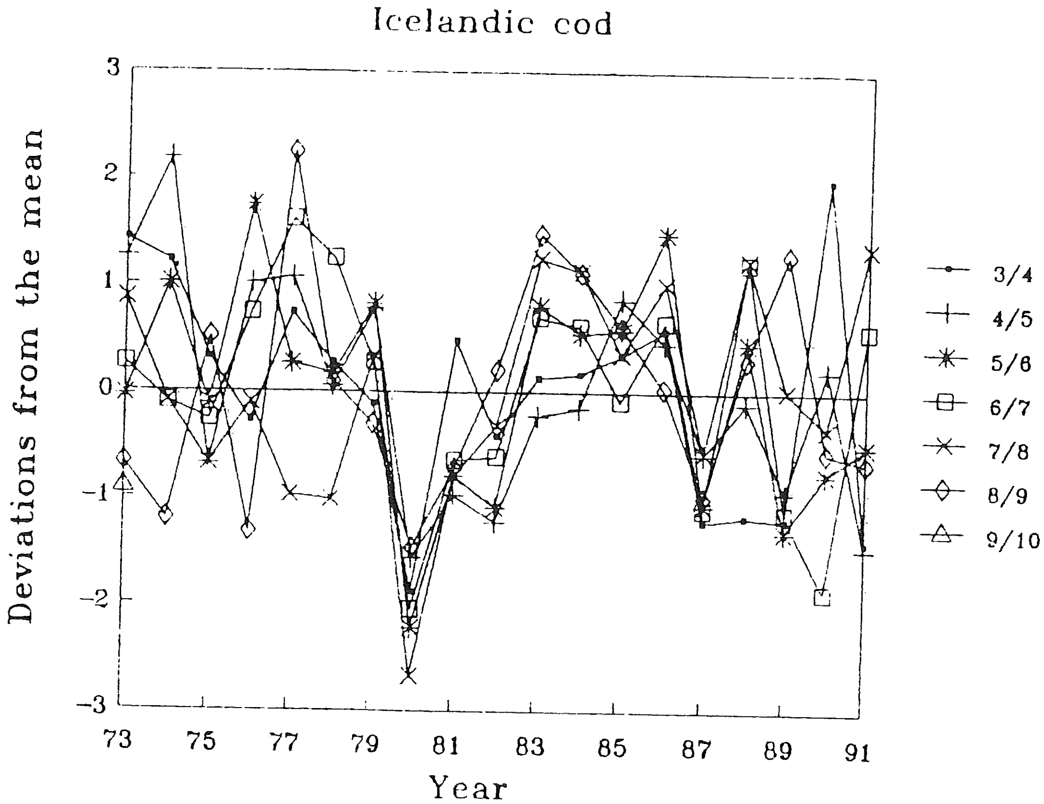


Fig. 1.- Growth comparison of increases in mean weight at age for ages 3-8 in standard units for North-East Arctic cod, together (above) and separate (below).



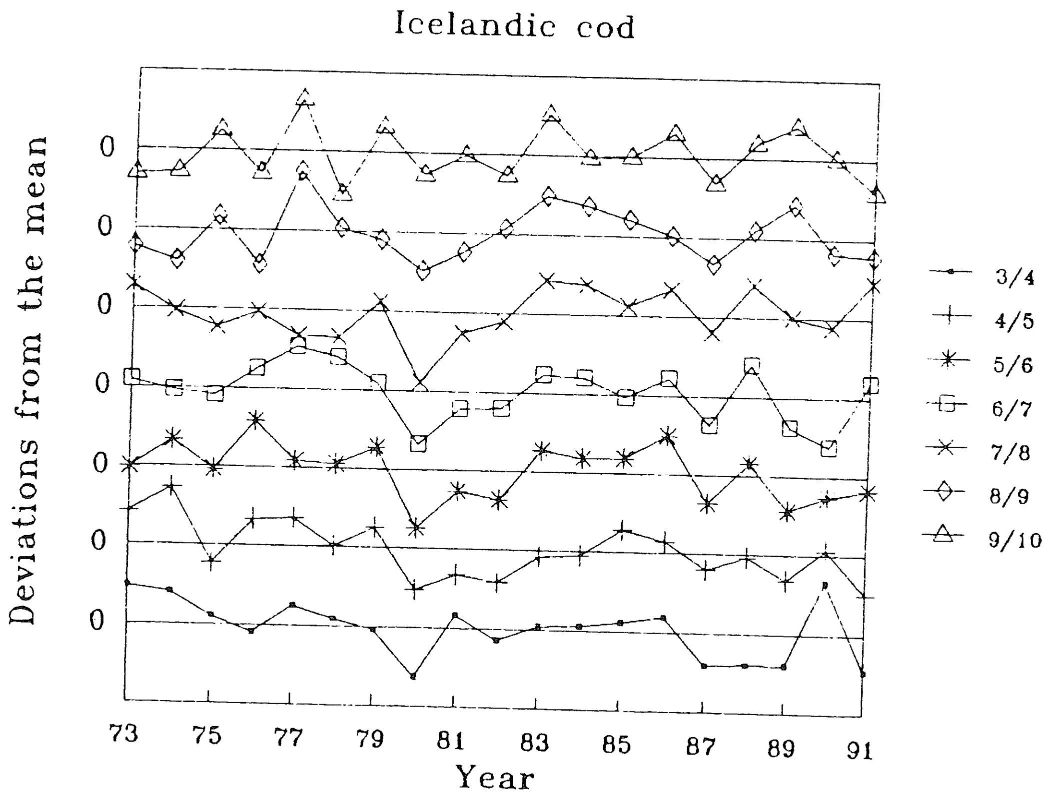
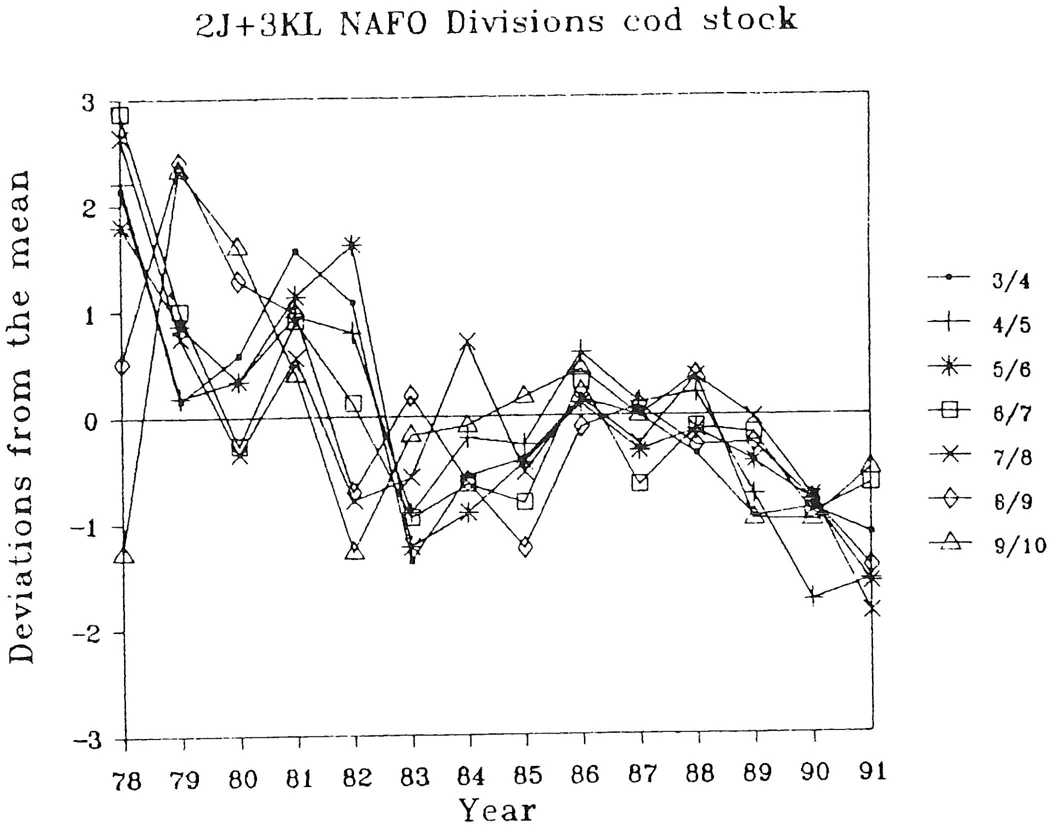


Fig. 2.- Growth comparison of increases in mean weight at age for ages 3-10 in standard units for Icelandic cod, together (above) and separate (below).



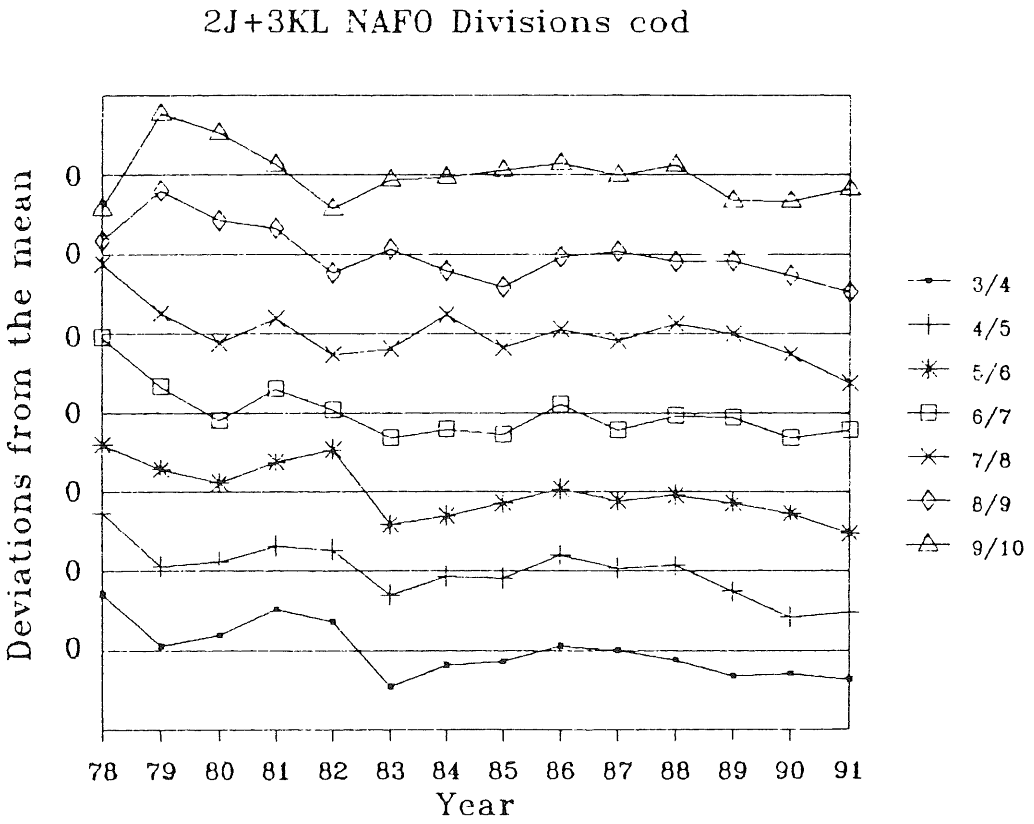


Fig. 3.- Growth comparison of increases in mean weight at age for ages 3-10 in standard units for NAFO Divisions 2J+3KL cod, together (above) and separate (below).

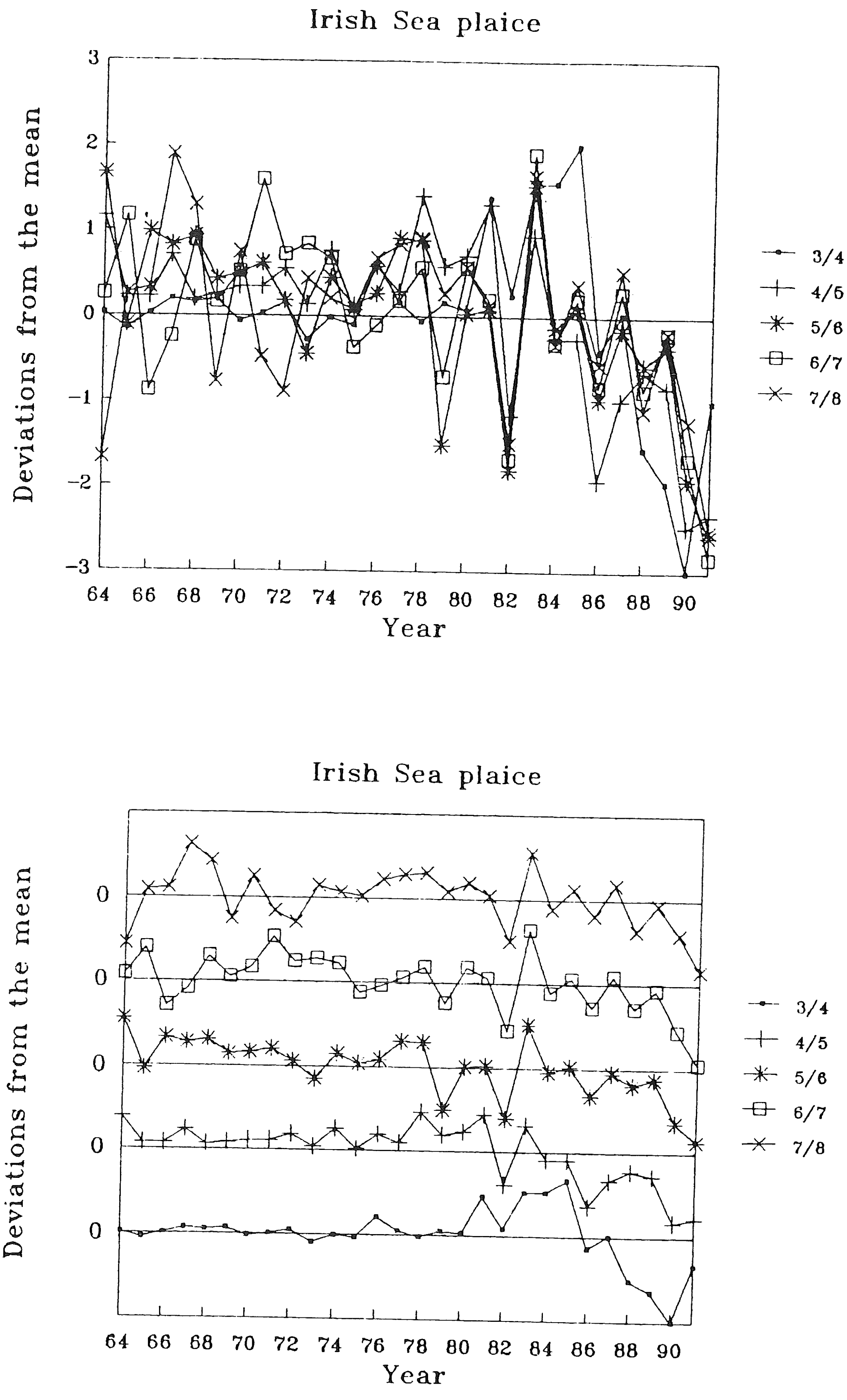
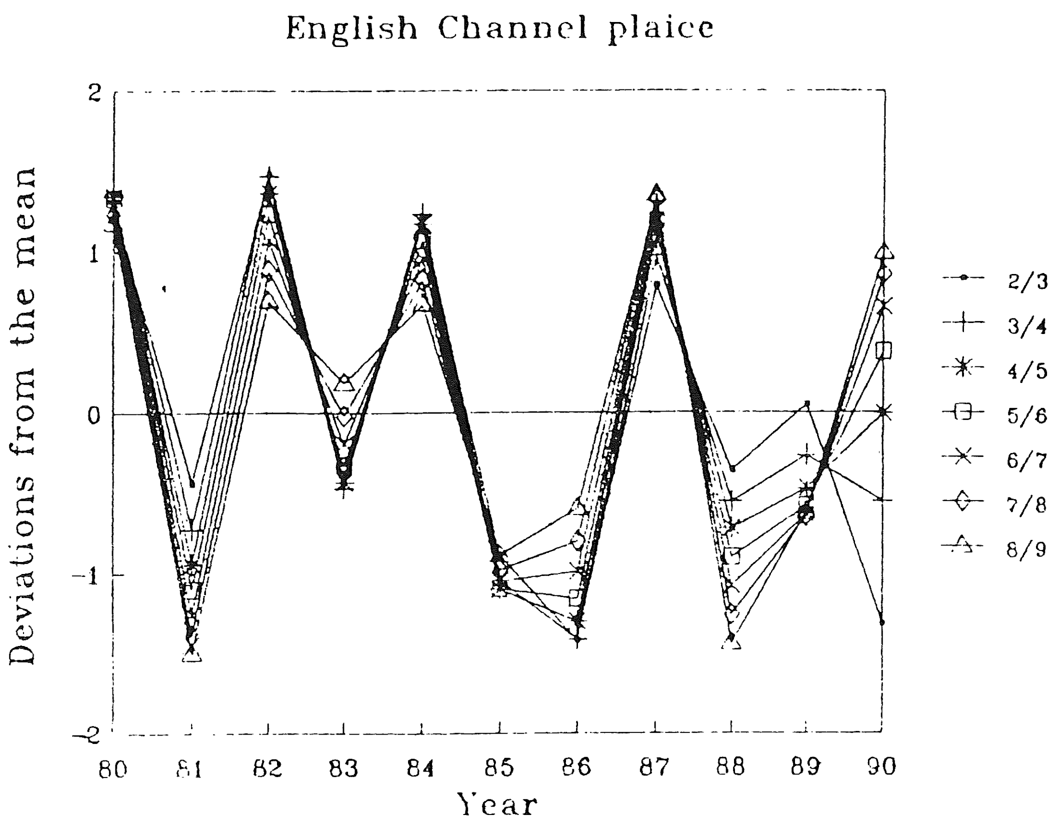


Fig. 4.- Growth comparison of increases in mean weight at age for ages 3-8 in standard units for Irish Sea plaice, together (above) and separate (below).



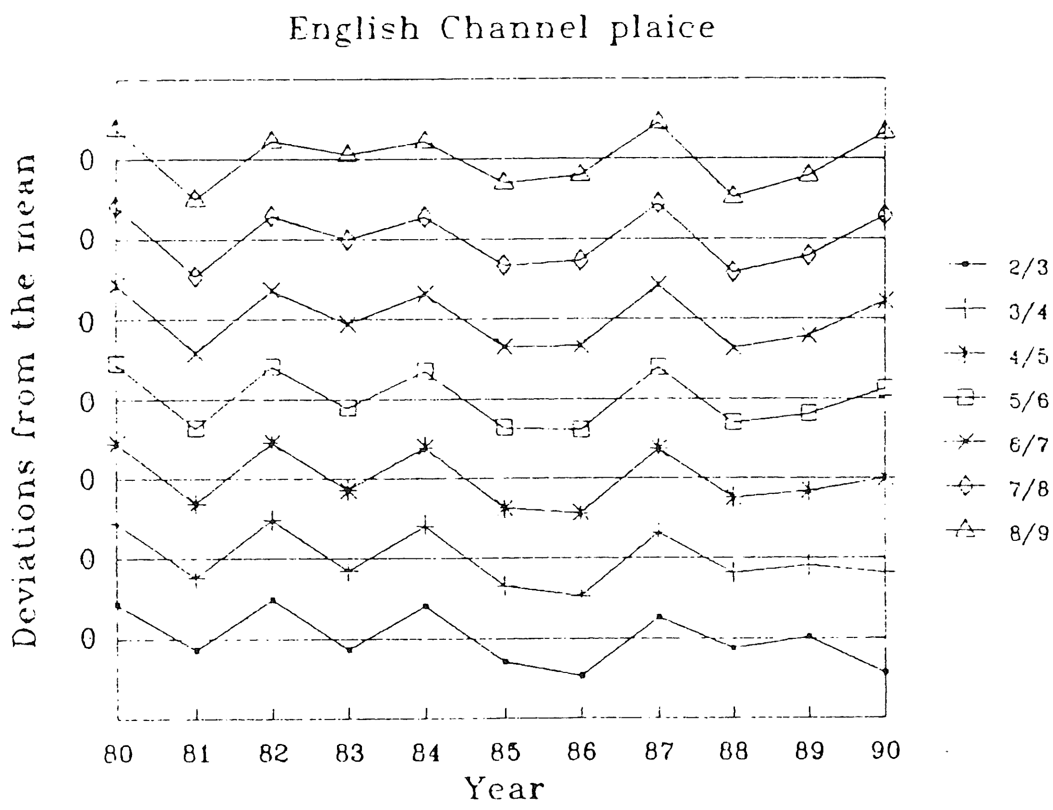


Fig. 5.- Growth comparison of increases in mean weight at age for ages 2-9 in standard units for English Channel plaice, together (above) and separate (below).

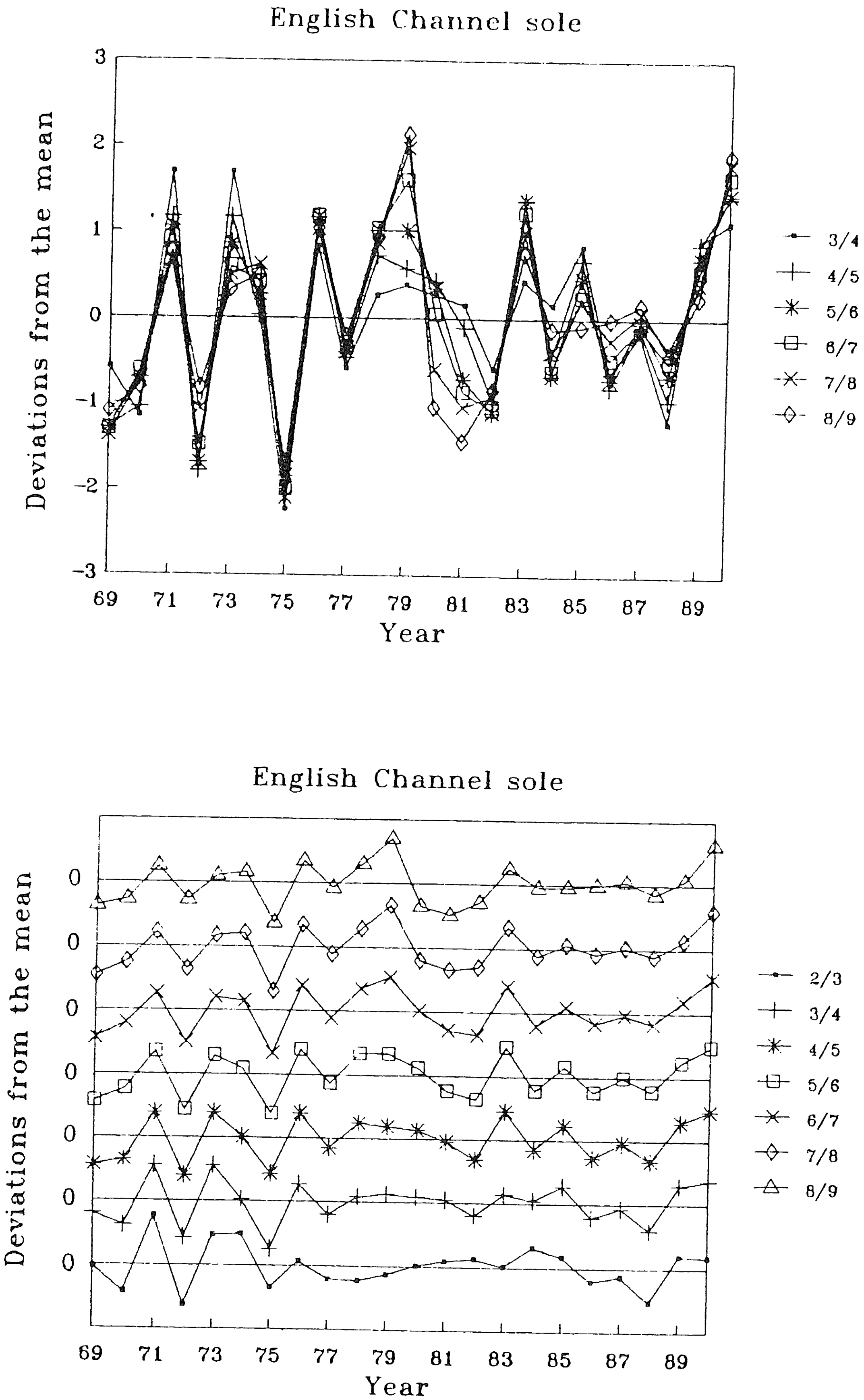


Fig. 6.- Growth comparison of increases in mean weight at age for ages 2-9 in standard units for English Channel sole, together (above) and separate (below).

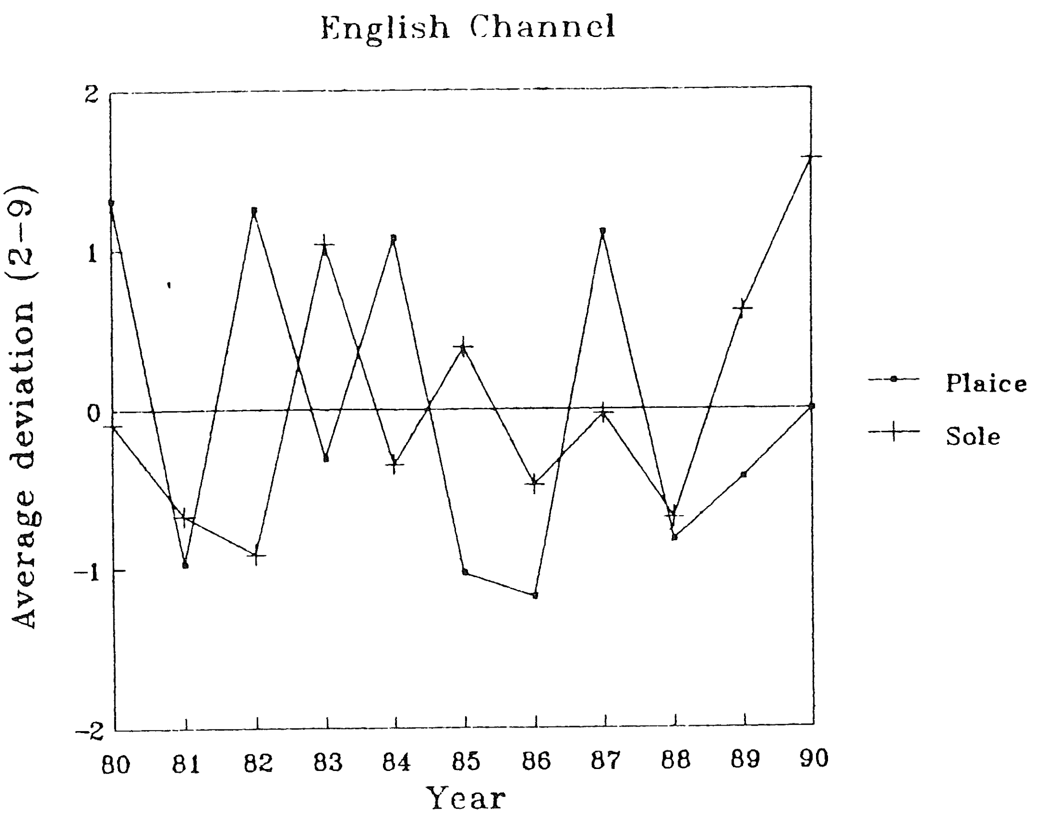


Fig. 7.- Comparison of average deviations (ages 2-9) for English Channel plaice and sole.

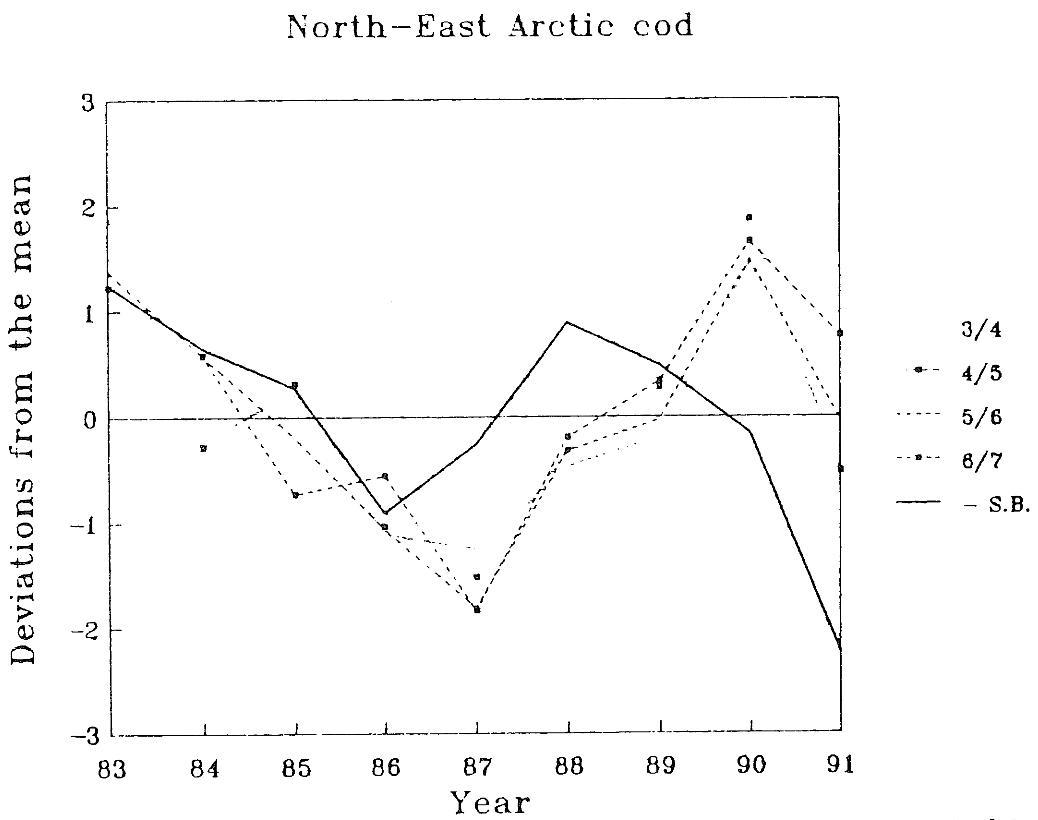
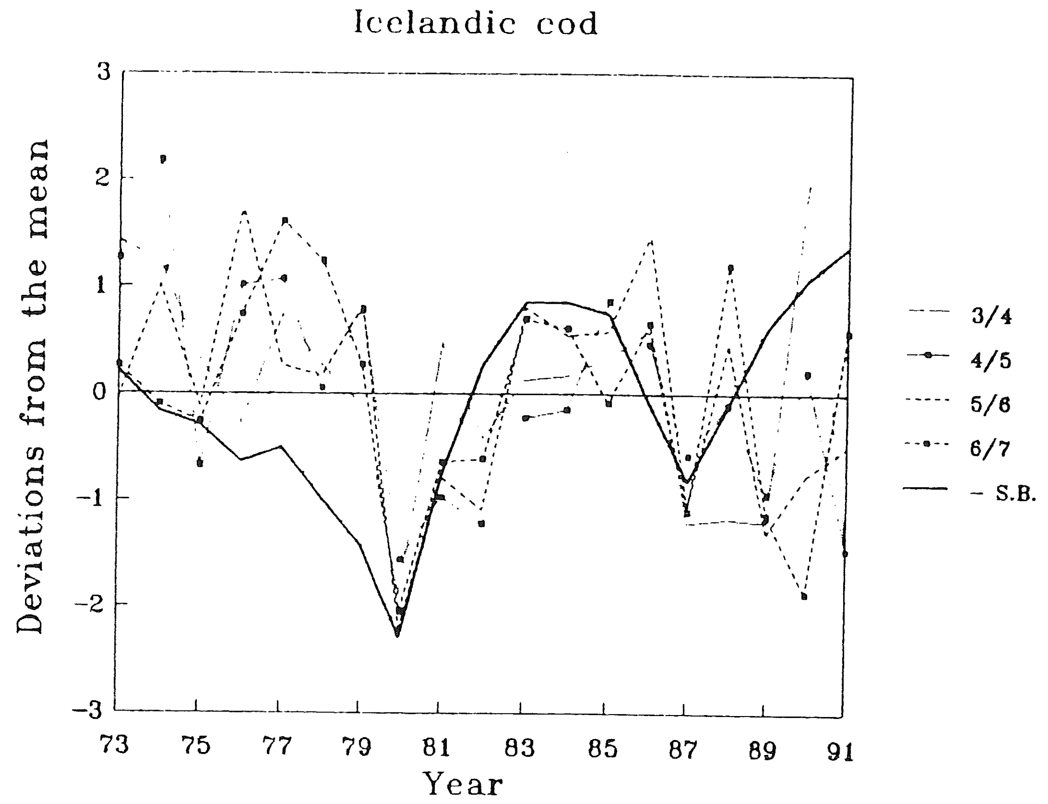


Fig. 8.- Growth comparison of increases in mean weight at age (ages 3-7) with the stock biomass sign changed, in standard units for North-East Arctic cod.



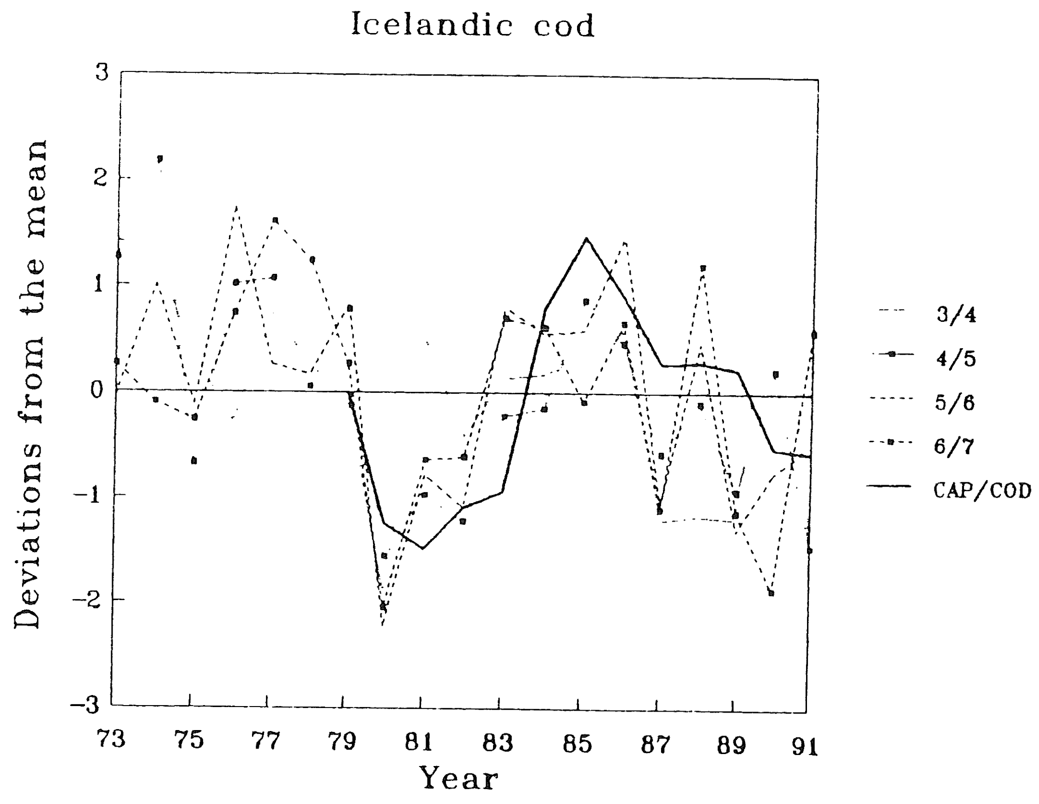
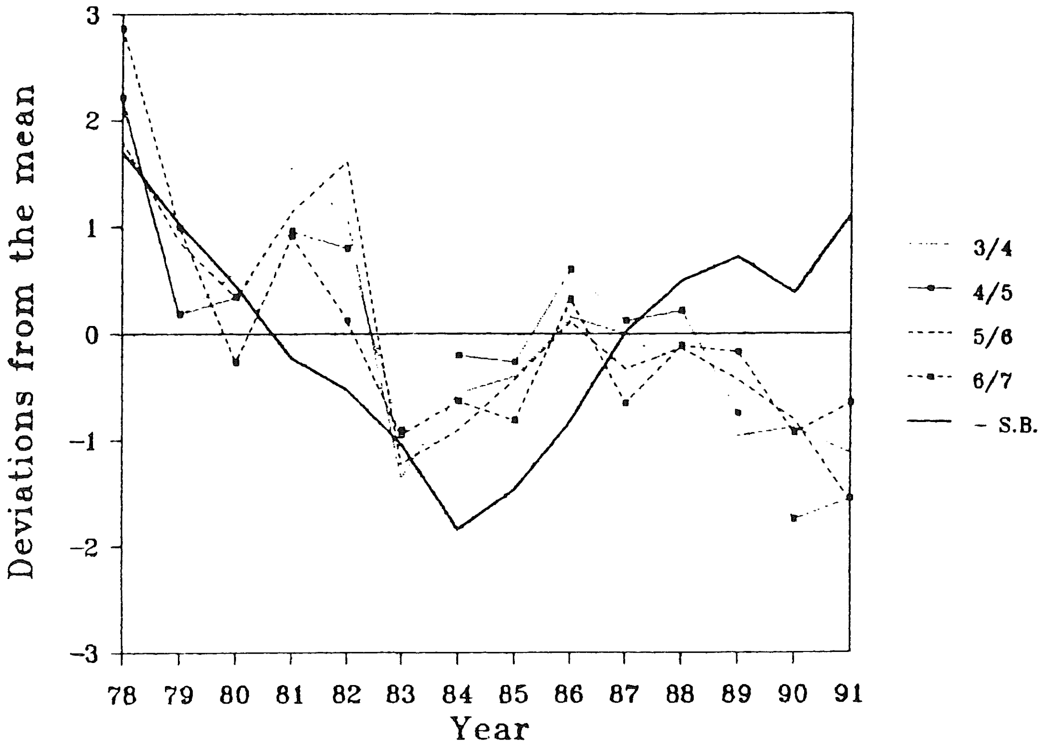


Fig. 9.- Growth comparison of increases in mean weight at age (ages 3-7) with the stock biomass sign changed (above) and with capelin/cod ratio (below), in standard units for icelandic cod.

2J+3KL NAFO Divisions cod stock



2J+3KL NAFO Divisions cod stock

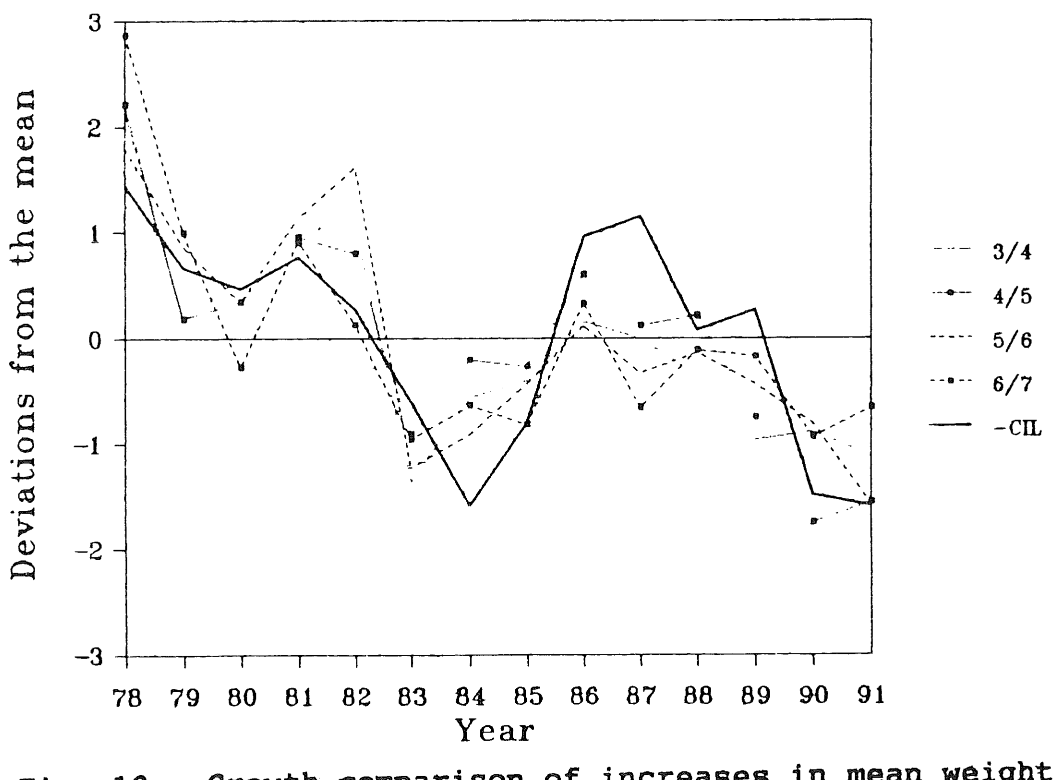
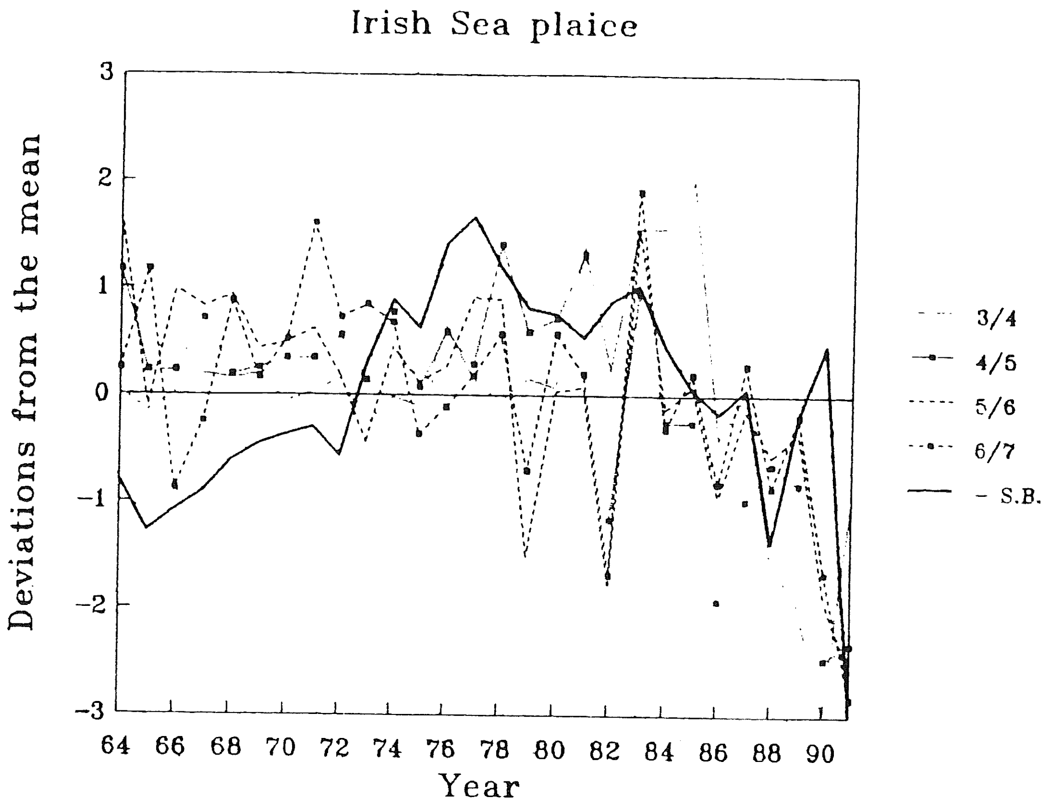


Fig. 10.- Growth comparison of increases in mean weight at age (ages 3-7) with the stock biomass sign changed (above) and with CIL area sign changed (below), in standard units for NAFO Divisions 2J+3KL cod.



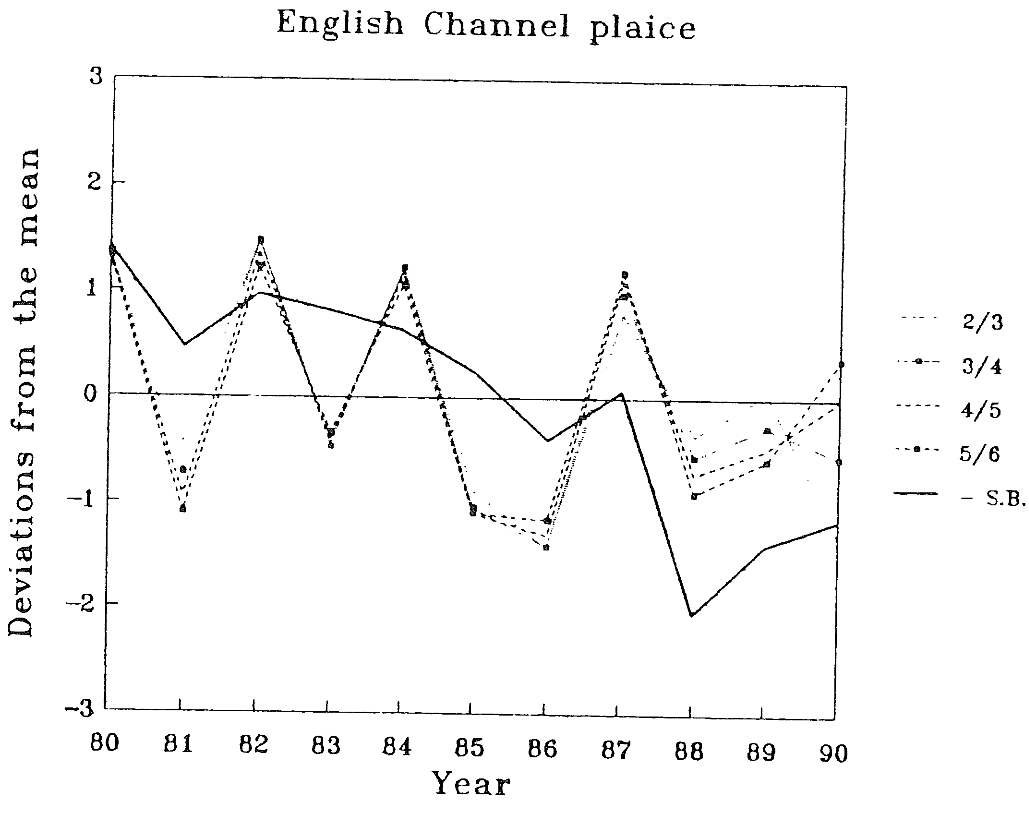


Fig. 11.- Growth comparison of increases in mean weight at age (ages 3-7) with the stock biomass sign changed for Irish Sea plaice (above) and English Channel plaice (below).

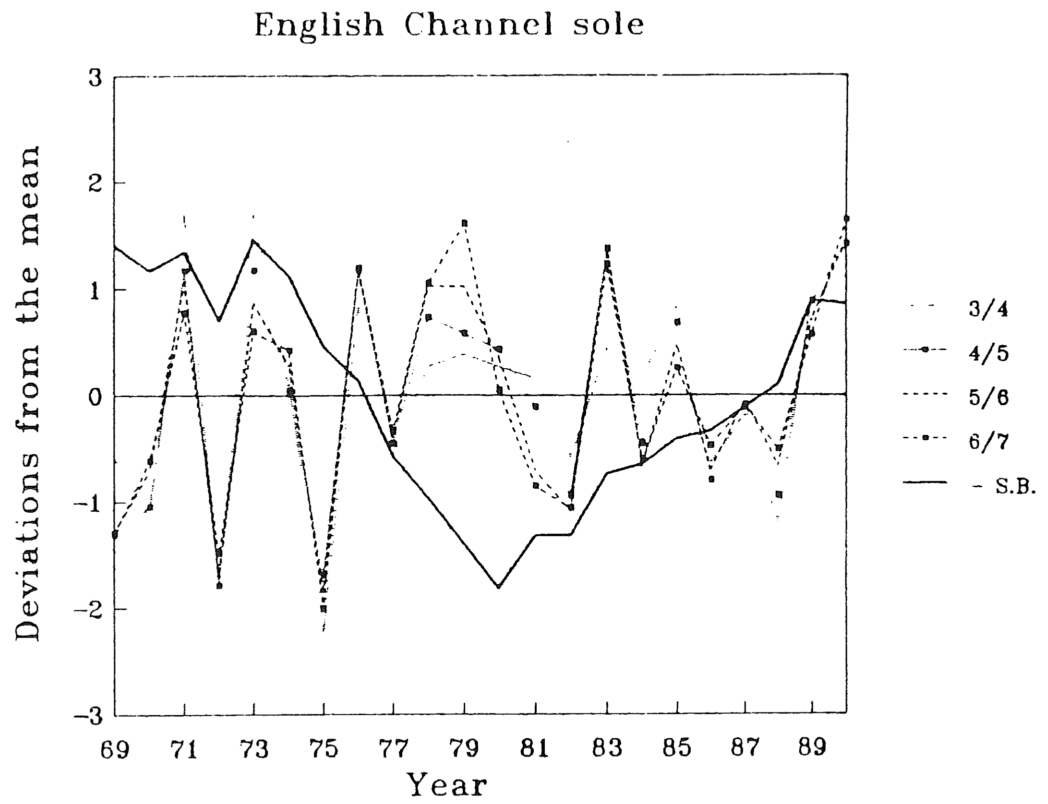


Fig. 12.- Growth comparison of increases in mean weight at age (ages 3-7) with the stock biomass sign changed for English Channel sole.

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ECOLOGICAL CONSIDERATIONS FOR STOCK ENHANCEMENTS

Working paper for ICES
"Workshop to evaluate the potential for stock enhancement"
May 19-24, 1994, Charlottenlund Slot, Copenhagen, Denmark

Jarl Giske
University of Bergen, Department of Fisheries and Marine Biology,
Høyteknologisenteret, N-5020 Bergen Norway

What follows is a discussion of the potential for increases of local stocks by mass releases of juveniles, based on results from the Masfjorden cod enhancement experiment. The discussion is intended to be general, but restricted to small scales (i.e. not the dynamics of the very great fish stocks) and strongly biased towards cod-like situations. I will not go into particular results from the Masfjorden cod enhancement program, as this has already been reviewed in detail by Fosså et al. (1993) and Smedstad et al. (1994), containing full bibliographies of the program.

Can we improve the natural output of local fisheries by releases?

There are at least two questions related to this: 1) (When) are stock sizes limited by recruitment, and 2) can we stabilize or increase the recruitment by mass releases?

The goal of the Norwegian cod release experiments was to level out natural variation in recruitment to local stocks. It was hoped that by releasing juveniles in years with low natural recruitment, a more even harvest could be achieved. The conclusions of the investigations so far are that the ecological basis for additional releases are only found in years when the natural recruitment is above the average. Mass releases can only be used to increase the difference between years, not to level them out.

Kawasaki (1980, 1983) classified fishes into three life history groups, differing in longevity and reproductive pattern, and hence with large differences in population dynamics. These categories are evolutionary responses to natural habitats and the expected variability therein. While Type II fishes are adapted to stable systems, Type Ia fishes are adapted to irregular variation in environment and fecundity by a potential high per capita growth rate r, and Type Ib is an adaptation to long-period variation, by high longevity and high adult survival. To this last category belong most if not all of the large exploited fish stocks, while examples of Type Ia fishes are species in the mesopelagic assemblage.

The interannual variability in recruitment, as Type Ib fishes are adapted to, may be caused by several factors. Feeding of fry and larvae will generally depend on available food, which for most species will be zooplankton (or organisms that eat zooplankton). And zooplankton availability will vary extensively on an interannual scale due to variability of current systems caused by weather fluctuations. It is very important to realize this trophic link between zooplankton production in remote areas, advective transportation to coastal areas and consumption by local planktivores. This variability both in water transportation and zooplankton concentration in the currents, is probably one of the more important factors contributing to year class strength variability.

This advection-driven variability is most pronounced for zooplankton, as their locomotory power is too weak to offset water transportation, and their reproductive rate too low to locally compensate for emigration losses. Planktivores will generally not "advect", although they may form enormous migratory schools. Also local phytoplankton concentrations will be more stable, as their renewal rate may exceed even a considerable water transportation rate. This implies that the carrying capacity of phytoplanktivores (e.g. clams) will be much more stable than of zooplanktivores.

Natural selection has formed fish life histories in such systems to make more offspring than what can usually survive in a good year; as the fitness cost of producing too many in a situation where almost all dies is less than the fitness cost of producing too few when many more survives. Thus there is a readiness to exploit both average and better-than-average situations. Local recruitment failure will be the result when unfavorable conditions have not advected masses of zooplankton to an area, and in this situation, releases of competitors will not improve the situation. However, if advection has been far above average, then local recruitment may be inadequate, and releases of ranged juveniles may contribute to the stock.

Local predator-prey dynamics will also by influenced by animal behaviour, and in a non-linear fashion. This behavioural component will probably be most non-linear at lower trophic levels, as the variability in food supply is greatest here. Individuals will continuously trade off their potential growth (by eating) versus their potential mortality risk (e.g. by feeding in exposed areas in stead of hiding) (Werner & Gilliam 1984, Aksnes & Giske 1990). If zooplankton concentrations are high, planktivores will have enough food and will tend to be "risk-averse" in their feeding behaviour. By so, their mortality rate is reduced, at the expense of (a very high) growth rate. The availability of prey to piscivores will therefore not be proportional to the increase in plankton. Similarly, if plankton concentrations are low, planktivores will have to risk more for a good meal, and food availability to higher trophic levels will be better than predicted from plankton concentrations. This, animal behaviour will even out some of the effects of physical variability (e.g. plankton advection), and the further up in the food chains, the more stable will the carrying capacities be. A corollary is that increased food supply to a population may increase its survival by reducing its predation mortality.

Can we predict oceanic variability?

For the economics of an enhancement program it would be necessary to know when and where mass releases may pay - and for this a tool for prediction of carrying capacity variability is needed. Meteorological events can not be predicted on an interesting time scale, while oceanic conditions may sometimes be predicted months or even years in advance (Dickson & al. 1988). However, the large-scale and interannual variability in oceanic copepod production is yet unknown. But as *Calanus* in northern boreal waters will have a seasonal vertical migration in the autumn to depths from where it can not be advected into shelf areas, there is perhaps a potential to monitor these stocks on a regional scale during autumn and winter in order to anticipate the seasonal influx of copepods in the following spring.

Life forms suited for enhancements

Very simplistic, one can say that the rate of production of a population will depend on its rate of food supply (although not in a linear fashion, as discussed above). This food supply can be increased by 1) increased local production, 2) increased supply of food to the population (advection, prey migration) or 3) by feeding migration of the predators. All large fish stocks are characterized by some kind of (adult) feeding migrations over extended areas (as well as by dependecy on advection to the start-feeding areas of their fry). A matrix of influence of geographic scale of predator/prey dynamics may be instructive to understand which animals may be suited for enhancements:

The production potential of the predator, based on the geographical behaviour of predator and prey:

PREY	PREDATOR	
	Stationary	*Migratory*
Locally produced	low, stable	high, stable
Advected to area	high, unstable	high, stable

The cultivation of Atlantic salmon in rivers is based on a migratory predator that may search for moving prey over large areas. By this, neither predator nor prey will depend on local conditions, and the dynamics of the predator may be expected to be much more stable than we may expect of coastal cod or saithe, fully dependent of receiving food aid from outside. However, the stationary predator depending on advected prey may still expect to gain far more food resources than a stationary predator who is dependent on the local production. Such, it has been estimated that if cod in Masfjorden should feed on the local food chain: locally produced phytoplankton - locally produced zooplankton -

nearshore fishes - cod, the fjord could only hold a stock of 1000 individuals. This is more than 2 orders of magnitude below natural densities.

Another aspect of food supply is the trophic position of the organism. Food and energy-contents of ecosystems are generally peaked in the lower trophic levels, and the potential for harvest will decrease with the trophic level of the catch. Algae-feeding bivalves thus have a much higher carrying capacity than piscivorous fishes, but this depends also on the level of advection of zooplankton to the area. Individual growth vs survival trade-offs will act to even out resource variability between trophic levels, as will also the increased longevity of prey at higher trophic levels.

A critical question for the success of releases is at which age the strength of a year class is establised. Release strategies must depent on whether younger year classes will suffer from competition or predation from elder individuals, and also whether the benefit of mass releases in a year with high advection will depend on high advection in the next year(s), also. Both these effects influence the survival of codlings in Masfjorden.

The philosophy of releases of juvenile salmon is that the oceanic conditions allows a far larger adult stock than the river may allow for juveniles. For stationary organisms, production will strongly depend on the rate of food supply, i.e. the rate of advection of prey. If this rate is approximately constant, one cannot expect gain from enhancement, while that may be possible for a variable advective supply. Salmon is an example of a two-stage life history with different food bases and mortality risks. As both marine diets and mortality risks generally are size-dependent, many species will experince this shift, to some extent. In such cases, growth and survival in the second "niche" may be independent of survival through the first. If conditions are poor for early life stages, releases of individuals who have been reared through this "bottleneck" may enhance the adult population.

However, it is also possible that populations are so local that recruitment may be hindered by extensive advective losses. This will particularly apply to species with low swimming ability and with pelagic larvae, as may be the case for large benthic crustaceans. Although they may feed on benthic prey, their continuous food supply will often depend on advective transportation of food to this community. Such populations are probably the principal candidates for a biological effect of stock enhancements. If they even are prized well, there may be economical gains in enhancing population sizes of such organisms by artificial recruitment.

The early Norwegian efforts to increase stocks of cod was done by releasing large numbers of yolk-sac larvae. However, as daily mortality rate at that age may be 0.1 day^{-1} over prolonged periods, there must be need of an enormous amount of larvae to enhance recruitment to even a small local stock. 10 % daily mortality over 4 months implies that only $\exp(-0.1*120) = 6*10^{-6}$, or six survivors for each million larvae released (see discussion in Salvanes & al. 1994). Tveite (1971) could therefore not detect any effect of these releases in fjords in southern Norway. Recruitment programs will only be successful if the larvae are kept in a low-mortality environment until they have grown to a size or age that make them less vulnerable to high natural mortality. For benthic crustaceans, this will of course mean not to release them before they may settle in the benthic habitat. So also for cod: mortality risk for pelagic cod larvae forbids an economically based release of such small individuals.

A major obstacle for economic gain from mass releases is the openness of the marine systems. Biologically, this means that carrying capacities are variable and often unpredictable over some time scale. The same openness may cause ownership conflicts which may be equally difficult to solve.

Habitats: geography and topography of carrying capacity

The question *What characterizes a good habitat?* may not receive the same answer as *What characterizes a habitat suited for stock enhancement?* For individuals, habitat profitability depends on a relationship between growth and survival potentials (Aksnes & Giske 1990) and individuals free to move will seek the locality that will maximize their fitness. From the resource management perspective, habitat quality will also depend on the same factors: how fast and how much will they grow, and how many will survive.

Local habitat quality is not of great interest for enhancement of migratory predators, as salmon. For stationary predators feeding on advective prey, local topography will be of utmost importance for local carrying capacity. (Stone age people knew that increased water transportation implied higher fisheries yield, and settled along narrow straits with strong currents.) The physical energy for advective transportation will be reduced inwards from the continental margins, and in Norwegian fjords there seems to be a reduction in carrying capacity from the coast inwards (Salvanes et al., in press). Also, the bottom topography, particulary the declination of the shore, determines the area that may be utilized by benthic sublittoral fishes like Norwegian coastal cod.

The other important factor for habitat quality is survival. Availability of local shelter is a better measure of habitat quality than actual number of local predators, as even more predators may be attracted to a mass release site. If the released organisms are territorial, then increased habitat complexity in form of shelter may also reduce the territory sizes and hence enhance the maximum population density.

While openness is a prerequisite for high food supply in plankton-based food webs, it also allows emigration of released fishes if conditions are unfavorable, and immigration of competitors if conditions are good. These migrations will dampen the effects of physical variability on the carrying capacity, and reduced the economical gain of an enhancement. And these competitors should be taken into account: stock enhancement will seldom affect only the enhanced stock, but also its prey, predators and competitors. Considerations of community effects must be part of a sustainable use of an ecosystem.

For a habitat to be suited for stock enhancement, there must either be a mismatch between local reproduction and local carrying capacity (e.g. local lobster fields), a bottleneck in growth or survival (e.g. salmon) or an interannual but for scientists predictable variability in carrying capacity (e.g. coastal cod). If one of these factors operate, and the species' biology is relevant for mass releases, then the next steps will be economical, legal and environmental considerations.

Acknowledgements

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ASSESSING TROPHIC IMPACTS OF FISH STOCK ENHANCEMENT[1]

by

Villy Christensen
International Center for Living Aquatic Resources Management
North Sea Centre, P.O. Box 101, DK-9850 Hirtshals, Denmark
Fax: (+45) 33 96 32 60. E-mail: V.Christensen@cgnet.com

Abstract

Trophic impacts can change the outcome of stock enhancement programs radically. At present quantified descriptions of such impacts are however rarely encountered, the present contribution therefore introduces some simple methodologies for quantification of trophic flows in ecosystems. In addition some examples are presented and attempts are made to simulate the effect of stock enhancement on a real and an artificial system. The methodologies are ECOPATH II, a system for balancing of steady-state ecosystem models and calculation of network flow indices, AUTOMOD a generic simulation model for treating incomplete data sets, and a length based multispecies virtual population approach presently under development.

Introduction

In the thirties Foerster found high mortality rates for young sockeye salmon (*Oncorhynchus nerka*) during their fresh-water life. In subsequent studies Foerster and Ricker (1941) through persistent gill-netting drastically reduced the abundance of predaceous fish feeding on young sockeye and demonstrated that this led to marked increased survival of the sockeye.

In a study of introduction of 0- and 1-group pikeperch (*Stizostedion lucioperca*) to control large populations of small planktivorous prey fish in a Dutch lake van Densen and van Grimm (1988) found this to be a promising technique.

For two American lakes Bauer and Willis (1990) demonstrated how introduced triploid grass carps (*Ctenopharyngodon idella*) could successfully control vegetation in one lake where largemouth bass (*Micropterus salmoides*) was the only top-level predator, whereas no impact on vegetation could be demonstrated in the other lake where the dominant predator Northern pike (*Esox lucius*) was likely to feed on the introduced carps.

[1] For presentation at the ICES Workshop to Evaluate the Potential for Stock Enhancement, May 19-24, 1994, Charlottenlund Castle, Denmark.

These are only a few cases meant to provide a pointer to the role of trophic interactions for successful stock enhancement. There are many more studies available, most of them trial-and-error examples from enclosed freshwater systems where researchers have tried to manipulate systems or have found that components of the systems have manipulated their work. Yet, we want to do better than merely empirical approaches but are faced with a lack of reliable, simple methodologies to predict the effect of introductions.

The purpose of this contribution is to point to some simple methodologies of use for including trophic considerations in stock enhancement programs. A first condition for doing better is that we understand the systems we want to change through stock enhancement. As lack of understanding of "natural" mortalities in ecosystems appears to be a dominant cause of enhancement failure -- over and over again since Dannevig's time -- we must focus on trophic interactions in ecosystems. As we further want to quantify these interactions and subsequently alter them an ecological modeling approach is called for.

Model methodologies and data requirements

Mathematical models for use in stock enhancement must be simple. In contrast to models for environmental applications it is not possible, nor feasible or desirable, to study the symphony of processes that merge to shape the ecosystem foundation (nutrients, phytoplankton dynamics, etc.) Such bottom-up modeling has been used successfully for environmental designs but to my knowledge never successfully to manage fisheries. For such purposes emphasis must be on the upper trophic levels notably the fished components. Add to this that the methodologies must be simple enough to be of use to scientists without specialization in modeling, i.e. for the fisheries biologists involved in stock enhancement, and we end up with only few tools of practical interest, e.g., network and multispecies analysis.

The data requirements for producing fisheries-oriented models of the sort discussed here must be minimal if the models are to be used. To briefly describe the 'minimal situation' I will give a brief overview of data requirements below.

Before embarking on this a warning is called for. What we are about to embark on may well be impossible; we cannot predict how Nature will react to a given perturbation in a given situation. We may however be able to give indications for the likely reactions to such perturbations, and certainly, by making ecological considerations an integral part of stock enhancement programs we only risk improving the success of such programs.

Data requirements

Catches:

The first and most important form for data to be collected from an area is catch statistics. For fished areas catch statistics linked with interviews of fishers will provide the necessary basic information about the ecosystem resources.

Species composition:

The dominant groups of the ecosystem must be identified. For stock enhancement purposes focus may well be on the upper trophic levels.

Standing stock:

Biomasses of the ecologically important groups should be monitored initially or periodically. Over time numerous methods have been developed for this, important is however that as high a precision as needed for traditional fish stock assessment may not be required. This open for use of methodologies as swept-area, visual censuses, etc.

Production (or mortality rates):

The total mortality rates of the important species may be obtained through traditional age-based assessment or length-based assessment, e.g., using FiSAT[2]. Short cut methods include use of empirical relationship, as an example Hoenig (1983) from data for a variety of aquatic organisms suggested the use of

$$\ln Z = 1.44 - 0.984 \ln T_{max},$$

for estimation of total mortality (Z = production/biomass) from maximum age in years (T_{max}). Natural mortality for fish may also be estimated from the relationship

$$M = K^{0.65} \cdot L_{\infty}^{-0.279} \cdot T^{0.463},$$

(Pauly 1980), where M is the natural mortality ($year^{-1}$), K is the curvature parameter of the von Bertalanffy Growth Function ($year^{-1}$), L_{∞} is the asymptotic length (total length, cm), and T is the mean environmental temperature (T °C). If catches, C, and biomass estimates, B, are available total mortality, Z, can be estimated from

$$Z = M + F = M + C/B,$$

where F is the fishing mortality.

Estimates based on empirical regressions as above are not very precise, they do however provide reasonable (say ± 30%) ball park figures.

Consumption rates:

Scientists may spend years in the laboratory to obtain a consumption rate estimate for a given size group of a given species. One may however also produce approximate estimates from use of much less intensive analytical or empirical relationships. This can be illustrated by two examples:

Jarre-Teichmann (1992) presented a method based on Sainsbury (1986) and others where daily ration is estimated from diel variation in total weight of stomach content using an integrated estimation process involving ingestion and evacuation rates, asymptotic stomach contents and feeding times. A requisite for application of the model is that diel changes in stomach content can be found. Applications have however shown this generally to be the case, and that it is the exception when it does not work, e.g., for large sluggish predators in cold water where digestion time may be several days. The method is implemented and distributed in form of a PC software, Maxims[3].

As a more rapid alternative/supplementary approach empirical relationships may be used. One such is given by

$$Q/B = 3.06 \cdot W_{\infty}^{-0.2018} \cdot T^{0.612} \cdot A_r^{0.516} \cdot 3.53\, e^{Ft}$$

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[2] FAO ICLARM Stock Assessment Tool, the successor of LFSA and the Compleat ELEFAN, available within months from FAO and ICLARM.

[3] Contact the ICLARM Software Project, MC PO Box 2631, 0718 Makati, M. Manila, Philippines, for further information.

where Q/B is the annual food consumption/biomass ratio ($year^{-1}$), T is the mean habitat temperature (°C), W_∞ is the asymptotic weight (g) of the fish, A_r the aspect ratio (Fig. 1), and Ft the food type (0 for carnivores and 1 for herbivores).

The relationship given above was derived by Palomares and Pauly (1989) from 33 analytical estimates of Q/B for marine fishes, and could explain most of the variance in the data set (r^2 = 0.75). As later demonstrated by Palomares it works equally well with freshwater fish.

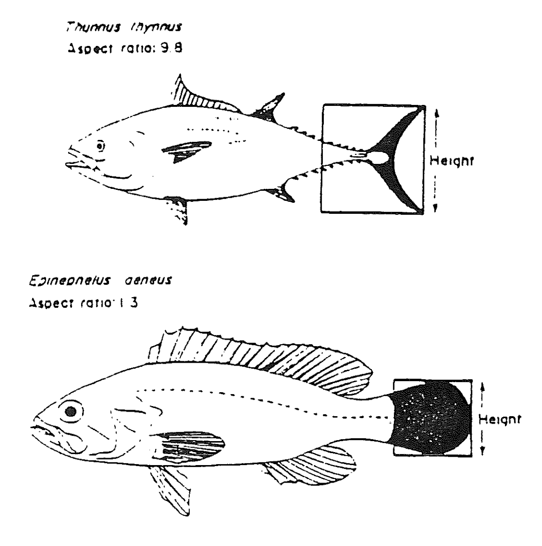

Fig. 1. Aspect ratio ($A = h^2/s$) of the caudal fin is estimated from height (h) and surface area (s, black).

Diet composition:

In spite of the now common phrase: "Everything eats everything" it is not impossible to quantify trophic interactions in a system. There will as a rule be a close relationship between the size of the predator and the size of the prey, (see, e.g., Ursin, 1973), also most fish are catholic at least to the degree that diets reported for a species from one area will not be fundamentally different from its diets in a similar area. Utilizing available estimates from the literature and locally obtained information reasonable diet compositions can be obtained for the major species from most areas.

As an example of data availability Larkin (1979) quotes J. C. Stevenson, then editor of *Journal of the Fisheries Board of Canada* for saying: "I sometimes think we should have a form paper entitled, 'the food of the blank in the blank lake,' and then authors would only have to fill in the numbers of fish sampled and the percentage of each kind of food, and we would be spared the agonies of editing." An important source incorporating not just such feeding information but all sorts of biological information about finfish, FishBase, is now about to be released[4].

Network analysis

Interest in network analysis for studies of marine ecosystems was formulated by the SCOR Working Group 59 more than a decade ago (Platt et al., 1981). Since then network analysis has been increasingly used as a diagnostic tool-kit for ecosystem structure, see, e.g., Ulanowicz (1986) and Mann et al. (1989).

A major reason for using network analysis is that it is a rather data extensive methodology where information of network nodes (ecological groups in our case) and their interactions is weaved together to form a network stronger than the component threads.

[4] FishBase is a scientific database being developed jointly by ICLARM and FAO and is planned to include published information about all (20,000+) fish species of the world. A first version has been released for testing, while a more comprehensive version containing information about 10,000 species will be released on CD-ROM in September, 1994.

A simple and readily available starting point for network analysis has been presented recently in form of the ECOPATH II[5] system for studies of trophic interactions in ecosystems (Fig. 2, Christensen and Pauly 1992b). For ECOPATH analysis the living parts of an ecosystem is split into a number of ecologically related groups, and the interactions between these groups is then described based on readily available information (Christensen and Pauly 1992a).

Version 2.2 ECOPATH II April 1994

MAIN MENU

<E> Edit data
<H> Hard copy (printout)
<P> Parameter estimation
<C> Cycles and pathways
<R> Required primary production
<S> Sensitivity analysis
<N> Network flow indices
<A> Aggregation
<X> Export file
<B> SCOR/ECOPATH bridge
<Q> QUIT

Select Option:

Fig. 2. Main menu of ECOPATH II for DOS computers.

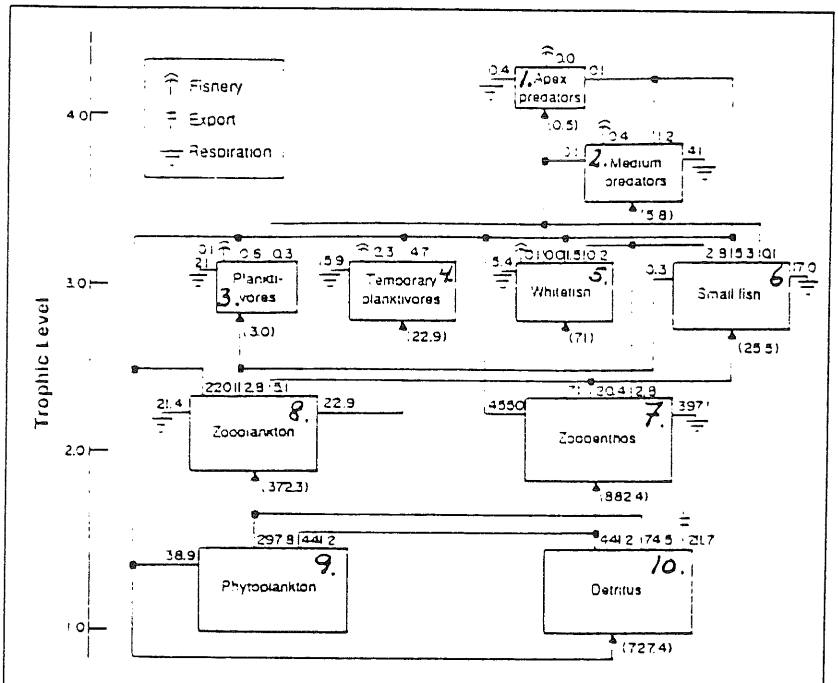

Fig. 3. Flow diagram for the Schlei Fjord ecosystem (based on Nauen 1984). Flows are in t ww $\cdot$ km^{-2} $\cdot$ year^{-1}.

To illustrate this Fig. 3 presents a balanced food web for the Schlei Fjord (Christensen and Pauly 1992b, based on Nauen 1984).

By placing the available data in a network as represented by the food web in Fig. 2 it becomes possible to evaluate data compatibility and various analysis can be performed. A first is examination of the sensitivity of the model to pinpoint crucial data. This is demonstrated in Fig. 4 for the two top predators in the Schlei Fjord ecosystem.

[5] ECOPATH II is a Public Domain software developed at ICLARM and up to now distributed to some 300 scientists. Numerous applications are documented in the volume "Trophic Models of Aquatic Ecosystems" released jointly by ICLARM, ICES, and Danida in May 1994.

In addition the balanced flow system open up for a number of other analysis, e.g., mixed trophic impacts, trophic transfer efficiencies, estimation of required primary production to sustain catches. Some of these are introduced briefly below.

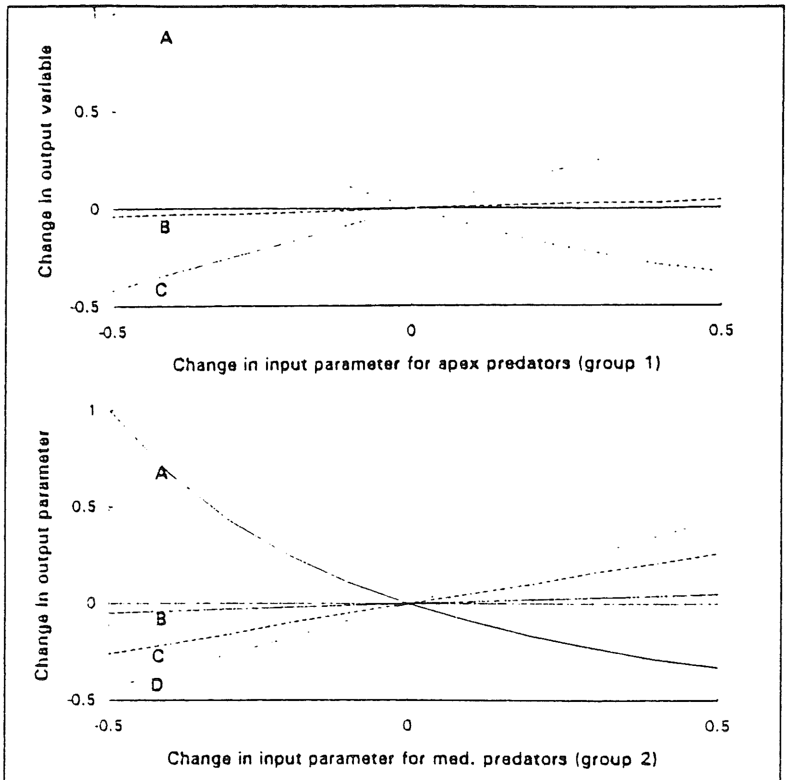

Fig. 4. Sensitivity estimates for the two top predator groups in the Schlei Fjord ecosystem model. Each input parameter is varied from -50% to + 50%, and the impact this has on each of the estimated parameters is then calculated. Only parameters sensitive to changes are shown. *Top graph*: Impact of apex predator (pike and pike perch). A is of their biomass (B) and production/biomass (P/B) on their own ecotrophic efficiency (EE); B is of their B and consumption/biomass (Q/B) on the EE of whitefish; C is of their B and Q/B on the EE of planktivores. *Bottom graph*: Impact of medium predators (perch, eel and flounder). A is of their B and P/B on their own EE; B is of their B and Q/B on the EE of zoobenthos; C is of their B and Q/B on the EE of whitefish; and D is of their B and Q/B on the EE of small fish.

Mixed trophic impacts:

Quantification of mixed trophic impact is based on economical input-output analysis as developed by Leontief (1951) and introduced to ecology by Hannon (1973). It is included in ECOPATH II based on the approach developed by Ulanowicz and Puccia (1990). The mixed trophic impacts routine quantifies the direct and indirect trophic impacts that any of the groups in the system (including the "fishery") has on any of the other groups. The mixed trophic impacts for the Schlei Fjord ecosystem are shown in Fig. 5.

An example of how to interpret the mixed trophic impact graph in Fig. 5: in the Schlei Fjord the fishery is dominated by the temporary planktivores, i.e. herring. As can be seen from Fig. 5 these only have a minimal impact on the other groups on the lower trophic levels in the system as they only spend a small part of the year in the Fjord. They do however compete with the two top predators as shown by the negative impacts they have on these.

The mixed trophic impact graph contains a wealth of information about how the ecosystem components influence each other trophically in a given situation, and as such it is a valuable tool to enhance our understanding of ecosystem interactions. The impacts cannot however not be used for prediction of, e.g., the effect of stock enhancement. This is mainly because the analyses are based on an assumption of constancy in food compositions. This assumption cannot be expected to hold if for instance a prey species becomes more abundant because of stock enhancement or good recruitment. In such a case one would expect the predators to switch and take a large proportion of their diet from the more abundant group.

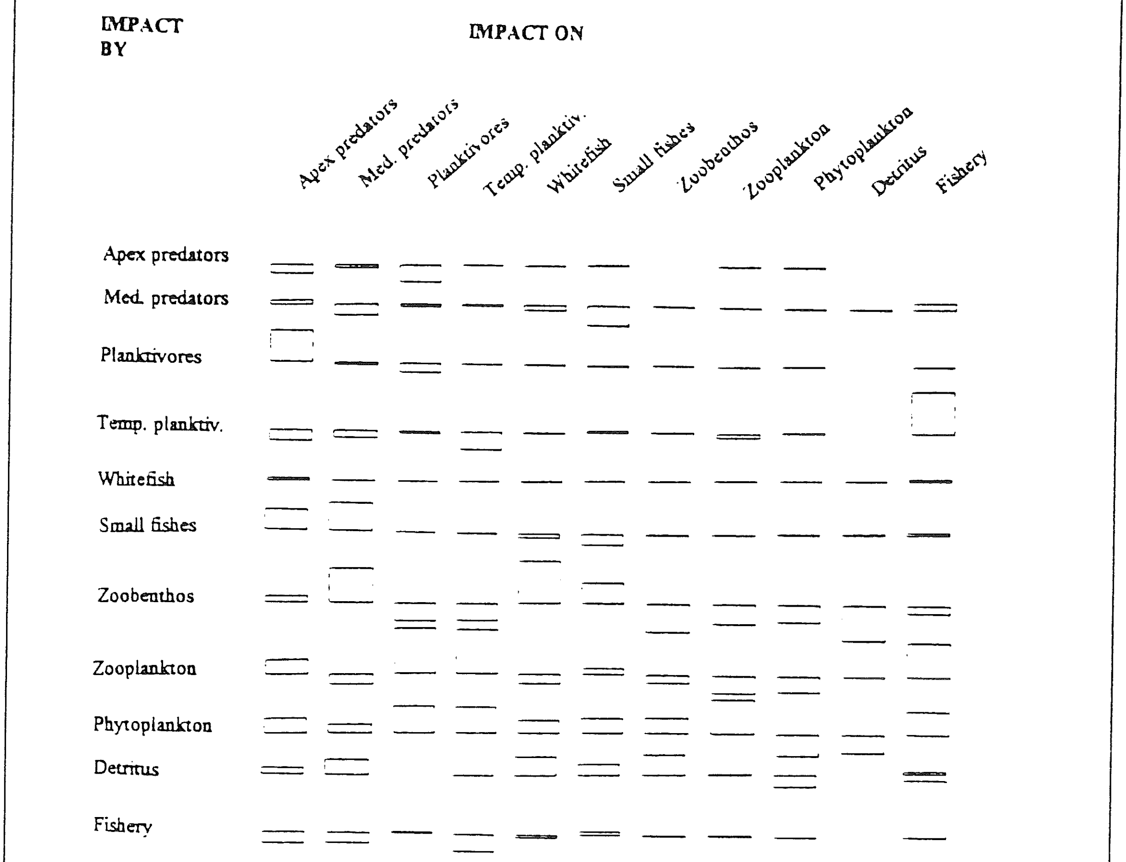

Fig. 5. Mixed trophic impacts in the Schlei Fjord ecosystem model. The figure shows how the groups given on the left impacts the other groups in the system. Positive impacts are shown above the imaginary baseline, negative below. The impacts are relative, but comparable between groups.

Selection indices:

Tentatively one may play with changes in abundance such as discussed above assuming that the predators show a constant electivity in the system. By first increasing the biomass of the enhanced group one can observe what impact this has on the selection indices (of which two are calculated in ECOPATH II, Ivlev's electivity index, Ivlev 1961, and a standardized forage ratio, Chesson 1983). One can then iteratively change the diet compositions of the predator(s) until the selection indices for these are as in the original run of the model. The changed diet will result in changed predation and one can from this get an estimate of how much of the releases that may be lost due to predation.

To illustrate this game we can try to double the production of the medium predators (i.e. of perch, eel and flounder) in the Schlei Fjord model from 0.51 $g \cdot m^2 \cdot year^{-1}$ to 1.02 $g \cdot m^2 \cdot year^{-1}$. This will result in the standardized forage ratio for apex predators feeding on medium predators decreasing from 0.085 to -0.255. Changing the diet of the apex predators iteratively until all of its prey have the same forage ratios as in the original model the consumption of medium predators is found to increase from 0.10 $g \cdot m^2 \cdot year^{-1}$ to 0.17 $g \cdot m^2 \cdot year^{-1}$. The implication is that of the increased production of 0.51 $g \cdot m^2 \cdot year^{-1}$ some 0.07 $g \cdot m^2 \cdot year^{-1}$ is estimated to be eaten by the apex predators. As the apex predators are assumed not to increase -- they are being held back by lack of breeding possibilities and an intensive fishery (Nauen 1984) -- the increased predation on medium predators is counteracted by a decreased predation of planktivores (less 0.04 g · m^2 · $year^{-1}$), whitefish (less 0.01 g · m^2 · $year^{-1}$), and of small fish (less 0.02 g · m^2 · $year^{-1}$).

The test run shows a problem related to doubling the production of medium predators. The enhancement will result in an increased predation on whitefish (plus 0.16 g · m^2 · $year^{-1}$), small fish (plus 2.8 g · m^2 · $year^{-1}$), and zoobenthos (plus 2.8 g · m^2 · $year^{-1}$). Of these groups only the zoobenthos can sustain the increased predation, and it can be concluded that the medium predators would have to change diets and take proportionally more zoobenthos, less whitefish and small fish.

It should be emphasized that what is presented here is only a "game", i.e. not all factors are considered, and not all assumptions may be met. Still it is feasible scenarios that are studied, and it may improve our understanding of trophic interactions in ecosystems.

Ecological valuation:

The "price" for sustaining the different components of an ecosystem varies depending on their trophic status. One way of accounting for this is in form of how much primary production is required to sustain the different groups in the system. Using a new routine of ECOPATH II (Version 2.20+) this can be quantified as shown in Table 1. As can be seen from the table the requirements increase as expected with trophic level up to a level for the apex predators where it takes 122-fold of primary production (and detritus) to sustain their consumption.

Table 1. Estimates of required primary production (PP) and detritus to sustain consumption for the groups in the Schlei Fjord ecosystem. Trophic levels are estimated from diet compositions. Paths are the number of trophic paths leading to each of the consumer groups. The last column gives the ratio between required PP and consumption.

	Group	Trophic level	Paths	Req. PP (and detritus)	Consumption	Req. / consumption
	Units:	-	-	g · m^2 · $year^{-1}$	g · m^2 · $year^{-1}$	-
1	Apex predators	4.1	20	61.3	0.5	122.6
2	Med. predators	3.5	8	171.0	5.8	29.5
3	Planktivores	3.1	6	21.8	3.0	7.3
4	Temp. planktivores	3.0	2	83.7	22.9	3.7
5	Whitefish	3.0	2	47.6	7.1	6.7
6	Small fish	3.0	4	154.5	25.5	6.1
7	Zoobenthos	2.0	2	882.4	882.4	1.0
8	Zooplankton	2.0	2	372.3	372.3	1.0

Using a similar routine the primary production required to sustain the fishery harvest can also be estimated. For the Schlei Fjord is found that a total of 161.3 g · m^{-2} · $year^{-1}$ is needed out of the total of 778.0 g · m^{-2} · $year^{-1}$ that is available, i.e. 21% of the available primary production is required to sustain the catches. For the fishery the ratio between required primary production and catches is 91, i.e. it is heavily influenced by the catches of apex predators.

Simulation based on network flows

Analysis of the form discussed above are based on balanced data, i.e. the input and output from each of the ecosystem groups are modified to balance. In ECOPATH II analyses this is done by the program which estimates one 'missing' basic parameter (biomass, production/biomass, consumption/biomass, or ecotrophic efficiency) for each of the groups. An alternative and more objective form for balancing of a static flow model was presented by Ulanowicz (1989) in form of the AUTOMOD[6] system. Ulanowicz chose a highly stable dynamic scheme in form of linear donor-controlled kinetics to infer the values of missing data and to balance the data set.

In addition to linear donor-control dynamics AUTOMOD also opens up for predator-control and as predator-control schemes are inherently unstable often causing extinction of ecosystem components, Ulanowicz also included a damped Lotka-Volterra type control with system responses both up and down the food web.

To illustrate the use of AUTOMOD a series of simulation was run on the

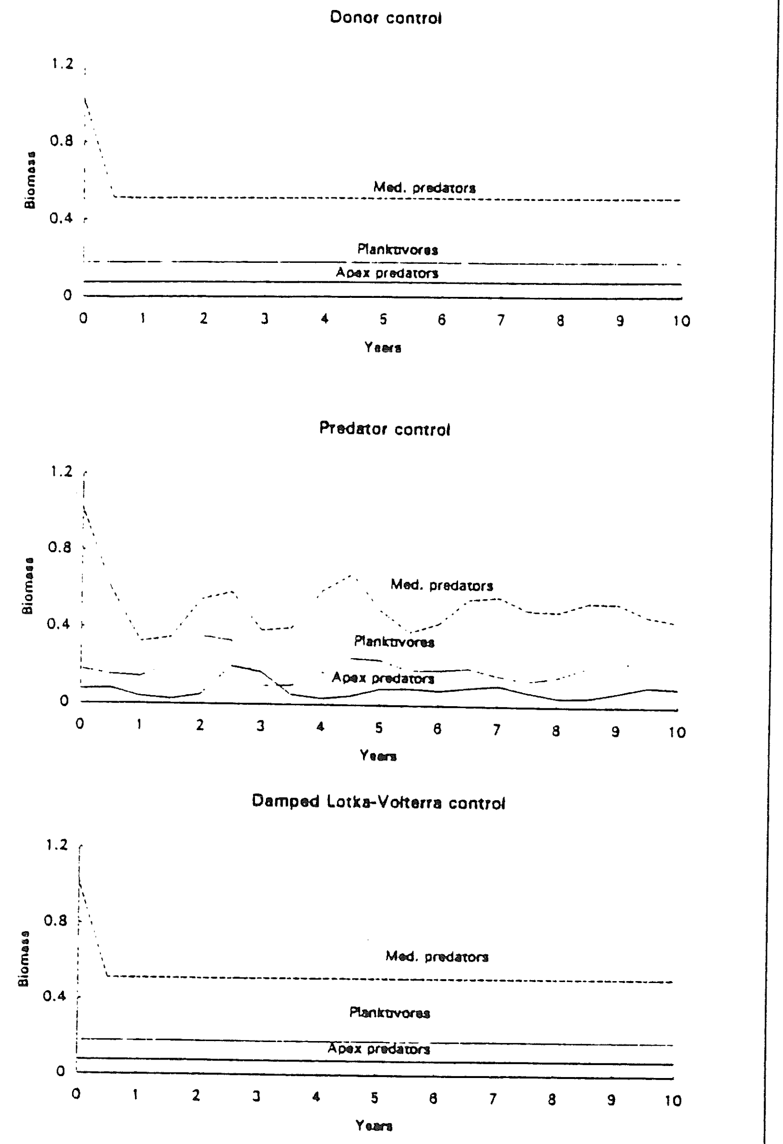

Fig. 6. Changes in biomasses for apex predators, medium predators and planktivores over three 10-year AUTOMOD simulations for the Schlei Fjord ecosystem.

[6] For further information about AUTOMOD please contact Prof. R. E. Ulanowicz, Professor of Theoretical Ecology, Chesapeake Biological Lab., Center for Environmental and Estuarine Studies, University of Maryland, Solomons, Maryland 20688-0038, U.S.A. E-mail: ulan@cbl.umd.edu (Internet).

Schlei Fjord data set (exported to SCOR format using the ECOPATH/SCOR bridge of ECOPATH II.) As in the example above the perturbation of the system consisted of a doubling of the biomass of medium predators. The reaction of AUTOMOD to this can be seen in Fig. 6.

The simulation with linear donor control (top graph) reverts to the original biomasses within 6 months indicating perhaps primarily that linear donor control is a robust method for balancing the network. The predator control option (middle graph) behaves in a fashion that can appropriately be described by Ulanowicz (1992) words. "The inherent instability of predator control seems to transcend even the predator refuge scheme for imparting stability. Not that the system blows up, but rather it meanders in what resembles chaotic fashion. It is possible that real systems behave somewhat in this manner, but it is unlikely that they respond so dramatically to small parameter changes." In this case there does not seem to be much reason to believe that the system will actually respond as shown on the figure, still one should not take the simulations as "realistic predictions of how the system would actually respond to the imagined perturbation" (Ulanowicz 1989) the purpose is only to simulate possibilities.

The third option, damped Lotka-Volterra control in this case produces results indistinguishable from those derived from donor control. The routine has shown more realistic behavior in other applications calling for a closer examination of its possibilities and characteristics.

Multispecies analysis

To expand on the above discussed network analysis other more data intensive methods can be considered. As stock enhancement includes release of fish for subsequent capture by fisheries it is of interest to use standard methods for fisheries management also for enhancement studies. Unfortunately, however, such methods have rarely been applied to enhancement, for one reason because useful methods are not readily available.

An interesting method for fisheries management that incorporates trophic impacts is the age-based multispecies virtual population analysis (MSVPA) now in use in the North Sea and Baltic areas. An introduction to the MSVPA is given by Sparre (1989). MSVPA in the form implemented in these areas comes however with a very heavy price tag because of the data demands. It may therefore be of interest to examine some simpler approaches. One reason why this may be feasible is that the questions addressed in connection with stock enhancements programs may well be much simpler than those addressed with the full fledged MSVPA. In stead of seeking to give recommendations for quotas the questions are rather: "Are there predators in the ecosystems that may have deleterious effects on the released fish?" or, "Are the released fish likely to prey heavily on other fish species of interest for the fisheries?" or "Is it likely that the released fish will have problems find sufficient food in the system or may they be competing with other fish groups for food?" Simpler question that may be addressed with simpler methods.

One such interesting approach was presented by Pope and Jiming (1987) in form of the Phalanx analysis, an extension of Jones' (1974) length cohort analysis to multispecies cohort analysis. Using the Phalanx analysis as a skeleton we have since made a test-version of a length based (LB) MSVPA (Christensen and Pauly *MS*). This LB MSVPA -- as the name tells -- incorporates a standard VPA equation for calculating fishing mortalities thus avoiding an import limitation of the former method. Also it incorporates Ursin's (1973) log-normal prey size selection function, Beyer's

(1987) unbiased estimator of mean weight, analysis of catches by fishing fleets, whereas estimation of rations is based on Pauly (1986). The LB MSVPA has been implemented in a test version and some preliminary analysis to show the relevance for stock enhancement can be presented here.

Pope and Jiming (1987) presented a three species example based on North Sea roundfish data, with a cod-like predator 1, a haddock-like omnivore, and a whiting-like predator 2. Here this example is elaborated further upon using where possible the same parameterization as originally. Additionally the catches have been allocated to three fleets: Fleet 1 are gillnetters taking mainly medium sized roundfish; Fleet 2 are boats using hook and line to take medium and large roundfish; while Fleet 3 include small meshed demersal trawlers catching mainly smaller fish (Fig. 7).

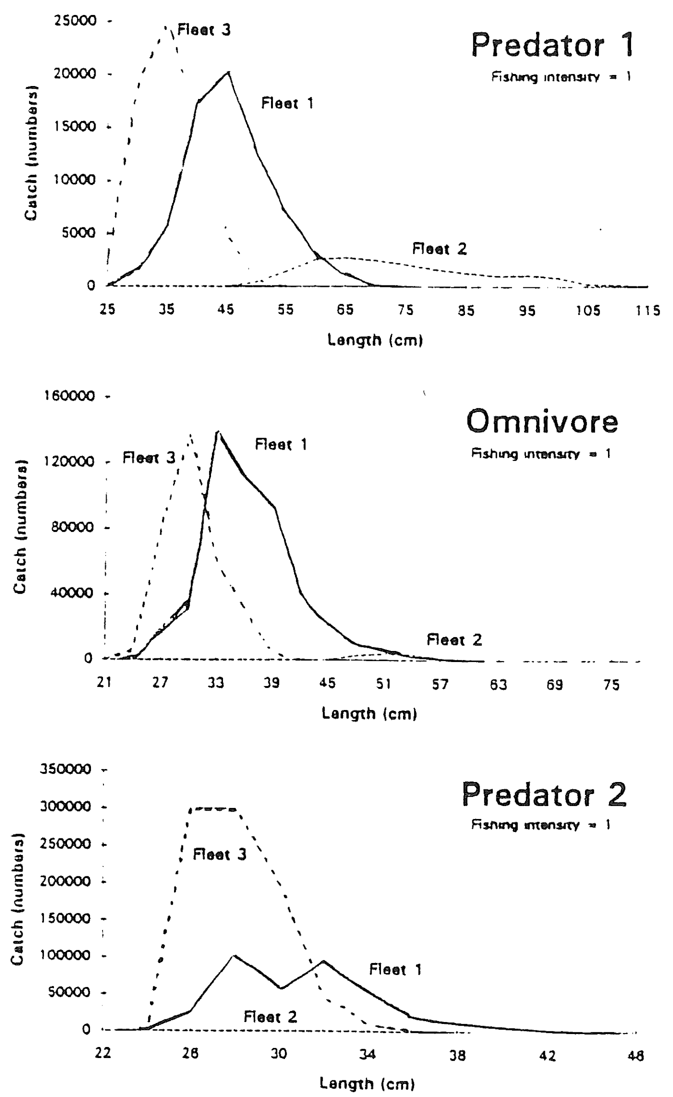

Fig. 7. Length distributions in catches of the three species caught by three fleets.

In addition to the LB MSVPA routine an inverse approach incorporating a LB MSFOR routine has been implemented to forecast future catches and size distributions based on variations in fishing pattern (and stock enhancement / recruitment). The present analysis are based on the use of the LB MSFOR routine. Data requirements for the analysis are described in Table 2 and Figure 7.

Table 2. Data requirements for the biological groups in an application of the length based multispecies virtual population analysis as implemented by Christensen and Pauly (MS).

Parameter	Predator 1 Cod	Omnivore Haddock	Predator 2 Whiting
Asymptotic length (L_∞ cm)	130	85	55
Largest length (L_{max}, cm)	120	81	50
No. of length groups	22	23	19
Length increment (cm)	5	3	2
Length/weight parameter a ($W = a \cdot L^b$)	0.000010	0.000009	0.000008
Length/weight parameter b	3	3	3
K (VBGF curvature parameter)	0.10	0.125	0.125
Food parameter β (from food conv. $K_1 = 1-(W/W_\infty)^\beta$)	0.07	0.1	0.1
Other mortality (size dependent but in this example assumed constant; equals 1-EE)	0.1	0.1	0.1
F/Z for largest length-group	0.7	0.7	0.7
Average weight ratio prey/predator (μ)	-4.6	-4.6	-4.6
St. dev. of weight ratio prey/predator (σ)	1.0	1.0	1.0
Suitability (predator 1, I)	1	1	1
Suitability (omnivore, I)	1	1	1
Suitability (predator 2, I)	1	1	1

For the 3 species 3 fleet example used here the results in Fig. 8 originate when for Fleet 2 (hook and line) and Fleet 3 (demersal trawlers) the fishing intensity is varied up or down with a factor of two.

The original situation (effort of both fleets at unity) represents a relatively high fishing intensity; we see however that in this simulation catches are increased nearly irrespective of how we change the effort.

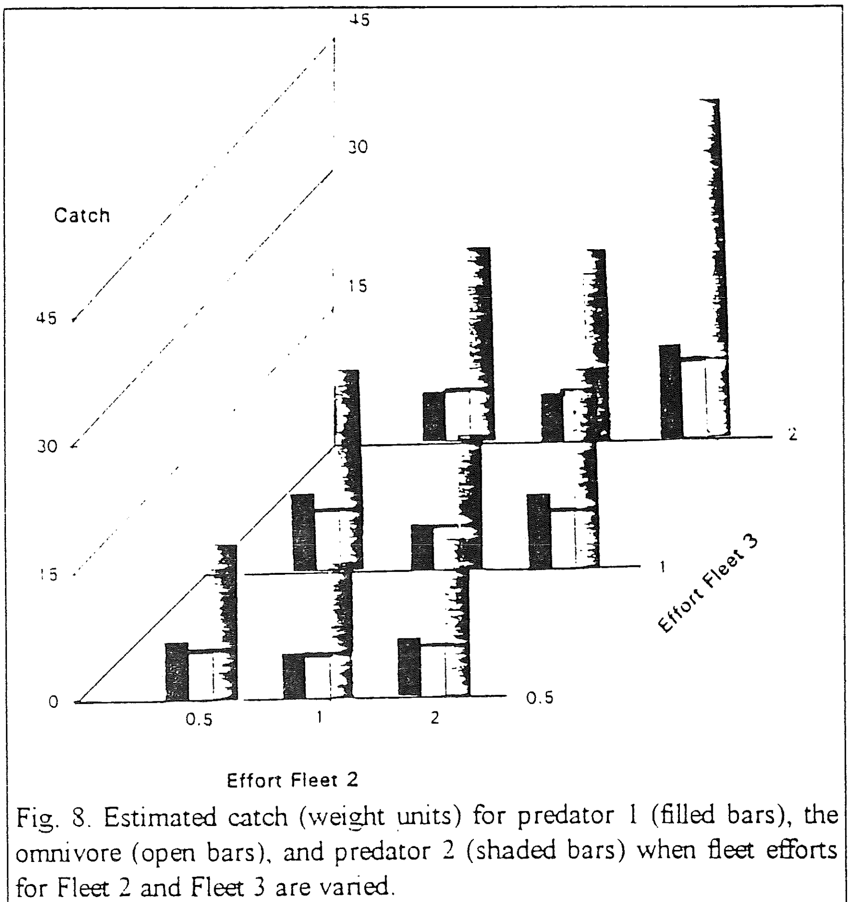

Fig. 8. Estimated catch (weight units) for predator 1 (filled bars), the omnivore (open bars), and predator 2 (shaded bars) when fleet efforts for Fleet 2 and Fleet 3 are varied.

Fleet 3 catches smaller individuals of all three species and we see that a doubling of effort for this fleet leads to increased catches. This however represent unsustainable situations where the biomasses are diminished severely, and this this may not represent wanted scenarios.

Changing the effort for Fleet 2 we see that an increase in effort leads to increased catches of predator 2 even though this species is not caught by the fleet. This is because increased fishing pressure on predator 1 causes less predation on predator 2 and therefore more is left to be caught.

When making a run of the LB MSVPA the number of fish in each length group is estimated for each species. This makes it possible to simulate the effect of stock enhancement by changing the estimated stock numbers and the use the LB MSFOR forecast routine to see what effect this may have on the catches and on the stock compositions.

Results of such a simulation are presented in Fig. 9 where the three curves shows the following three situations: (1) the original run; (2) a run where the number of fish in the each of the four smallest length groups of predator 1 have been increased ten-fold; and (3) a similar run where the number of fish in each of the four smallest length groups of predator 2 have been increased ten-fold. In all three simulations the fleets efforts are kept at the original level (corresponding to fishing intensity = 1 on Fig. 8).

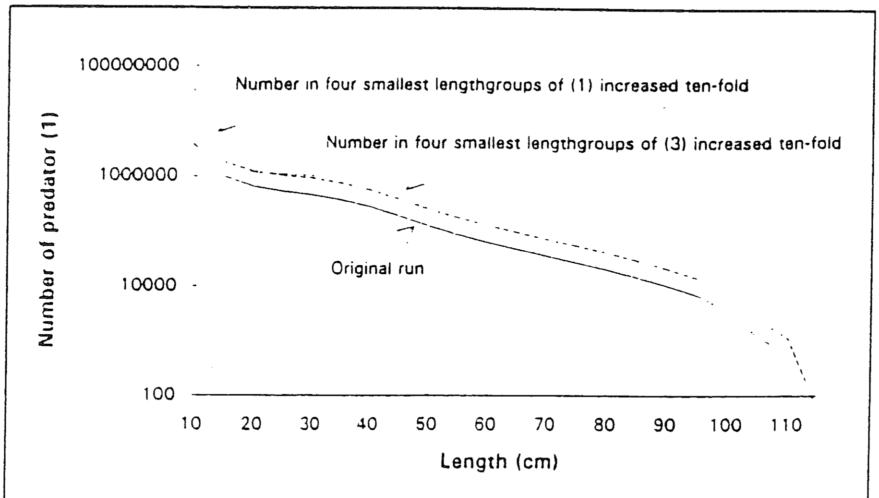

Fig. 9. Stock estimates (number) for predator 1 in three simulations all with the original fishing intensity (1) for all fleets. Group (3) referred to on the graph is predator 2.

The results for predator 1 (illustrated as this is assumed to be the species of main interest for the fishery) show the following pattern. The tenfold increase of small individuals quickly diminishes and the abundance's in the larger size classes are "only" around a factor two higher than in the original run. Interestingly the effect on predator 1 is as beneficial if it is predator 2 that is released in stead of predator 1. The explanation for this is that the dramatical increase in abundance of small individuals of predator 2 leads to the small of predator 1 being less exposed to predation, therefore more will survive to a larger size. The estimated changes in catches in the two stocking cases roughly follow the stock sizes, i.e. the catches are also estimated to approximately double.

What can be learned from an exercise like this? Not much of course, this is only a simulated case. The important aspect is however that the data requirements for this form for analysis are very limited, therefore the argument is that there is a good reason to go ahead and perform such simulations on actual data.

Acknowledgment

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ICES Workshop to Evaluate the Potential for Stock Enhancement, 19-24 May 1994, Charlottenlund Castle, Copenhagen, Denmark,.

The potential use of artificial reefs in stock enhancement strategies.

Jensen, A.C., Collins K.J. and Free, E.K.
Department of Oceanography, University of Southampton, Southampton, SO17 1BJ, UK.

Introduction.

Artificial reefs are used world wide in coastal management strategies ranging from habitat amelioration to fisheries enhancement. The sophistication of structures varies considerably according to material availability and level of technology required in design and deployment.

Japan are the world leaders in artificial reef technology for commercial fisheries enhancement and have been creating artificial reefs from 1789, and probably before this date (Ino, 1974). Currently the Japanese are in the third phase of artificial reef development, that of creating entire fishing grounds (Stone *et al.*, 1991) where there had been none before. This programme commenced in 1974 with the goal of converting Japanese fishing effort from distant water fishing to farming and resource management in Japanese waters. Government investment has been substantial, for example in 1988 US$150 million was destined for subsidising the construction of $2.2 \times 10^6 m^3$ of fishing reef. Materials used are generally considered to be "prime materials" ie concrete, steel and GRP. Whilst the engineering and design aspects of Japanese artificial reefs are well refined and standards have been produced which must be complied with if structures are to qualify for government certification the biological appraisal is not so well advanced. Mottet (1981) concludes that there are insufficient biological and economic data for judging the effectiveness of many of the operations.

In the USA the reefs programmes of many states are run for the benefit of recreational sports fishing, SCUBA diving as well as commercial fishing, waste disposal and environmental mitigation (Stone *et al.*, 1991). American experience dates back over 100 years and a wide variety of materials have been used from prime concrete to stabilised Pulverised Fuel Ash (PFA) to "materials of opportunity such as ships and train carriages. The USA has a national artificial reef plan (Stone, 1985) but no government funding commitment is attached to this plan. The most notable source of funding has been the Federal Aid in Sport Fish Restoration Program, providing up to 75% of costs, with individual states providing the final 25%. In 1987 more than US$140million was provided by the Federal Aid program.

In addition to the governmental plan individual states have local programmes and there are also some interstate agreements to promote a rational approach to the deployment of artificial reefs.

Elsewhere reefs have been developed locally according to requirement using materials judged to be suitable, only Japan and the USA have a national development plan. In South Australia Kerr (1992) reports a programme of creating artificial reefs utilising the large number of waste tyres available (Branden and Reimers, in press). In general Australian reefs have been created from materials of opportunity such as tyres and ships. Such reefs have been used primarily as a location for recreational angling with some SCUBA diving also taking place. The Maldives have utilised concrete structures to repair coral reefs damaged by dynamite fishing (Edwards and Clarke, 1992). Artificial reefs have been used in India as part of a programme to boost artisanal fishery captures, here the materials used were locally available bamboo and concrete tiles (Kadappuram, 1990).

In Europe artificial reefs were pioneered along the Mediterranean coast in the late 1960s. In 1993 a questionnaire asking for brief details of artificial reefs and their uses was sent to workers through-out Europe. The replies (Jensen, 1994) showed that in Europe most reefs are still associated with scientific research. Italy, France and Spain have been the most active between 1970 and 1994, currently Spain is placing more artificial reefs into its coastal waters than any other European country (Revenga, pers comm.). Reef building has, until recently, been carried out on a national basis, with little across border cooperation. Italian artificial reef scientists formed an Italian reef group in 1991 for liaison between research groups (Relini pers.comm.). An association of Mediterranean artificial reef scientists now exists (Fabi, pers. comm.). Current initiatives hope to form a network of European artificial reef research scientists with a view to establishing a future coordinated direction for reef research within the European Union. To date there is no overall European reef plan.

The majority of artificial reefs have been placed as nature conservation and /or habitat protection structures in the Mediterranean, the latter preventing trawlers from damaging fragile seagrass beds. Bombace *et al.* (in press) analysing the information of a questionnaire sent to report 69 artificial reefs deployed by Israel, Italy, France and Spain. There is a wide range of interest in the utilisation of artificial reefs in Europe. Poland, Russia and Finland are studying the potential of artificial reefs to act as biofilters near aquaculture sites, The UK and Italy have an interest in the environmental acceptability of stabilised waste materials such as Pulverised Fuel Ash from coal fired power stations. Researchers in Italy, Spain, France and Israel have programmes looking at the ability of artificial reefs to improve the efficacy of commercial fin-fisheries, whilst Spain and Italy have interests in mollusc culture on artificial structures. The UK, Italy and Israel are at varying stages of investigating the use of artificial reefs for lobster stock enhancement whilst Holland, Portugal, Turkey, Spain and Monaco have reefs placed to study epifaunal colonisation and/or for nature conservation.

Artificial reefs and lobsters, research to date.

It appears that only 3 countries, Canada, Israel and the UK have focused attention on artificial reefs as a specific lobster habitat. Canada built the first artificial reef specifically for lobster research in 1965 from quarry rock placed 400m away from minor lobster habitat, 2 - 2.5km from major concentrations of lobsters (Scarratt, 1968; 1973). Over the following eight years the lobster population of the artificial reef was monitored by diving scientists. The reef was initially colonised by large specimens of the lobster (*Homarus americanus*) (>41mm Carapace Length (CL)) thought to have outgrown their burrows, so being forced to seek new shelter.

By 1973 the size frequency distribution of the artificial reef population was similar to that on natural reefs in the area. Scarratt (1973) concluded that the sanding crop on the reef might be increased by a different configuration of rocks but that a cheaper source of reef material or a multiple use reef would be needed before an artificial reef could be considered an economically viable proposition.

In Israel, efforts have focused on the slipper lobster, *Scyllarides latus*, an important commercial species found off the Mediterranean coast (Spanier, 1991). These unclawed lobsters were found to inhabit tyre artificial reefs. Research showed that slipper lobsters preferred horizontal shelters with two narrow entrances on the lower portion of the reef. Shelter response is believed to be a major defence mechanism for these animals (Spanier *et al.*, 1988) and the presence of the artificial reef provided new and suitable habitat for colonisation. Slipper lobsters migrate into deeper water as the temperature rises but tagged individuals were seen to return to the tyre reef over a 3 year period (Spanier *et al.*, 1988). Spanier (1991) suggests that in the long term populations of these heavily exploited animals could be protected by building appropriately designed artificial reefs for slipper lobsters in protected areas such as underwater parks and reserves.

In the UK work has been undertaken from 1988 to date on an experimental reef placed in Poole Bay on the central south coast of England. Deployed on a flat, sandy, seabed in 1989 this reef, 3km from lobster habitat, was constructed from blocks of stabilised Pulverised Fuel Ash (PFA) to establish the environmental suitability of PFA in British waters (Collins *et al.*, 1991a). One aspect of this study was to assess the potential of reefs for fisheries enhancement. Within 3 weeks of deployment lobsters (*Homarus gammarus*) were present on the reef (Collins *et al.* 1991b). Tagging studies were initiated in 1990 and data to February 1994 shows that lobsters have found the artificial reef a suitable long term habitat, the longest period of residence stands at 1050 days (Jensen *et al.*, 1994). Conventional tagging of sub legal size (<85mm CL) lobsters in the nearby Poole Bay fishery has revealed that lobsters in the Poole Bay area do not undertake any seasonal migration, and that most movements averaged over time are less than 4km in magnitude (Jensen *et al.*, in press). The use of a novel electromagnetic telemetry system on the Poole Bay Artificial Reef has started to reveal complex local movement behaviour with nocturnal movement dominating, frequent changes of daytime refuge, multiple occupancy of the conical (1m high and 4m base diameter) reef units and some animals leaving the reef site for up to 3 weeks and then returning (Collins *et al.* in prep).

Diver observations and evidence from pot caught lobsters suggests that the Poole Bay artificial reef can support all aspects of the lobsters benthic life cycle; berried females utilise the shelters, some reproducing more than once on the reef, lobster stage 4 larvae have been taken from the waters above the artificial reef, a 27mm carapace length (CL) individual was caught in a prawn pot on the reef (it is likely that this lobster settled on the reef as a stage 4 larvae), and a wide size range of juvenile and adult animals have been captured and/or observed by diving scientists. Comparisons of the size frequency distribution of the Poole Bay fishery lobster population and that of the artificial reef have show statistically significant differences between the two groupings. This is thought to be due to the much larger proportion of the fishery population being of 80 - 85mm CL (just below legal size) than on the artificial reef. This reflects the greater proportion of 85mm CL and above animals on the artificial reef. Whilst fishing mortality is lower on the reef than in the fishery it is felt that this difference is in some part due to the greater proportion of large niches on the artificial reef in comparison to the natural reefs in Poole Bay.

Artificial reefs and fin-fish.
General comments can be made regarding the usefulness of artificial reefs to fin-fish enhancement. The nature of the habitat required will depend on the species under consideration and its requirements.

It is important to distinguish attraction from true enhancement. Artificial reefs are attractive to fish, concentrating the population and making it vulnerable to fishing pressure. Fishery managers need to be aware of this when considering the impact of a reef on a fishery. A concern about over-exploitation may be lessened by placing the artificial reef in a marine reserve, so creating a refuge from fishing pressure. Reefs provide shelter from predators and currents, for example the Poole Bay artificial reef attracts large numbers of O group pouting, *Trisopterus luscus*, which move position around the reef as tidal currents change, dispersing to feed at night. Artificial reefs may provide a habitat for a prey species. This will be of importance if food is considered to be a "bottle neck" in the stock.

Artificial habitat can be provided in a wide variety of types. It appears to be feasible to increase spawning areas by the provision of the correct substrate type. In the UK the Poole Bay artificial reef provides a significant number of crevices or gaps between the stabilised PFA blocks which are used as nest building sites by the male corkwing wrasse.

Already well established in the Mediterranean sea is the use of artificial reefs as a means of providing habitat protection. Areas of seabed of stock enhancement value, such as spawning sites and/or nursery areas may be protected by substantial structures capable of resisting the trawls of large fishing vessels.

Discussion
The role of artificial reefs in stock enhancement is primarily one of providing habitat. This can either be the creation of habitat where none had existed before or the modification of natural habitat to, say, provide an increased number of suitable shelters for lobsters in general, or of a given size range. A reef can be designed to provide the required shelters in sufficient numbers and size to minimise "off-reef" movement caused by the need to seek a new shelter after moult. Barry and Wickins, (1992) have published models that predict the number and size of shelters in a reef made up of perfect spherical boulders, a starting point for more realistic material dimensions. Design features do not have to just focus on one fishery species, providing a structure on the seabed will attract both benthic and pelagic species to the area and different species will be preferentially attracted by different types of reef profile and structural complexity.

Artificial reefs have been shown to effectively support three species of commercially important lobster. Questions have been raised about dilution of the natural population by increasing the habitat in a fishery by provision of an artificial reef. This would only be an initial effect before all niches were occupied, and could be minimised by careful siting. Work by Jensen *et al.* (1994) suggests that few lobsters (<85mm CL) would move more than 4km from their original capture location. A remote artificial reef could be supplied with hatchery reared juveniles with a good prospect of survival, such as seen in juvenile release experiments in the UK (Bannister *et al.*, 1994). At present the maximum densities of lobsters that can be achieved have not been established, but data presented by Scarratt (1973) for *H. americanus* suggests that the Canadian quarry rock reef supported 1 lobster per 6m^2 whilst the Poole Bay reef is thought to hold 1 *H. gammarus* per 2m^2. Neither structure was designed to maximise lobster habitat.

The economics of artificial reef construction are still being debated. The use of high technology concrete and steel structures with large scale construction techniques does not seem to be feasible in a UK context at present where there is emphasis on the lobster fishing industry paying fully for such structures. Grant aid from the European commission is possible, the EC supported 50% of Italian and Spanish and 89% of French reef construction costs in the past (Bombace *et al.*, in press) but this funding has yet to be explored from an UK context. Perhaps more realistically from a fisherman's point of view would be the use of environmentally acceptable "materials of opportunity" and low cost stabilised waste products such as PFA. Such materials could be deployed by a combined effort from fishermen, over a period of time, to create designed, multiple function fishing reefs at a low cost. At present UK legislation would not allow fishermen to have sole fishing rights for lobsters on an artificial reef that they have created, which is a major disincentive to any artificial reef programme being developed. It is expected that modified legislation will be passed by government in due course.

Whilst it has been shown that artificial reefs can support lobster populations over significant periods of time many questions regarding the way lobsters utilise a habitat remain to be answered. In order to maximise stocking densities and minimise "off-reef" movement lobster behaviour needs to be studied in greater detail. In the UK context this may include continuation of electromagnetic telemetry studies to detail localised behaviour and the deployment of an artificial reef designed to test some of the hypothesis of shelter size and density created during the past 5 years research.

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STOCK ENHANCEMENT AND FISHERIES MANAGEMENT

Alain Laurec and Willem Brugge
Commission of the European Communities (DG XIV)
Brussels

In a context where most of the scientific investigations on fisheries confirm the conclusions classically summarised as "too many fishermen are chasing too few fish" any suggestion that it could be possible to increase the available resources without "reducing fishing efforts" or "increasing mesh sizes" is very appealing. A simplistic perception of ranching or artificial reef programmes can lead some decision makers to believe that it would be possible to avoid unpopular management measures by promoting a "positive" approach, as opposed to the usual research necessary for conventional fisheries management. Such naive views can even exist among scientists who are not familiar with quantitative ecology and the long history of unsuccessful or, what is not scientifically better, inconclusive attempts for increasing fish resources through the release of artificially reared juveniles or habitat manipulations. This does not imply that such attempts are necessarily hopeless. But it implies that before a large scale, and presumably costly programme is launched, the various dimensions of the problems must be properly analysed, and that the dialogue between the scientific "promoters", the fishermen and the decision makers is sufficiently transparent and efficient.

The existence of a technique which makes it possible, through the development of aquaculture, to produce large quantities of juveniles cannot be a sufficient reason for developing a restocking or sea ranching programme. It is absolutely necessary to develop techniques for estimating survival rates, and to conduct cost benefit analyses. The same is true for the analysis of interferences, including those of genetic nature, between the released individuals and the natural populations of the same species. Economic analyses cannot avoid addressing the access right issues, which in other words implies an analysis of the "who will pay for, and who will benefit from" question. The same logic applies to artificial reefs, the development of which cannot be justified solely by a new engineering technique or the possibility of developing another descriptive marine ecology programme on colonisation of free substrates. Here again quantitative techniques are necessary for estimating the real impact of an artificial reef, and distinguishing it from the various statistical noises. The definition of fishing rights in the vicinity of the reef will also require socio-economical analyses.

A review of the various biological and economical problems should be a preliminary to any large scale programme. The methods to be developed are to a large extent common with the usual bioeconomic studies necessary to fisheries management. Population dynamicists will be necessary for assessing survival rates. Biologists will find exciting challenges for improving the survival chances of the released individuals, as well as ecologists who will have to develop their expertise for defining more efficient reefs. But for measuring survival rates or the impact of an artificial reef they cannot work without co-operating with highly qualified biometricians. In the same way, fisheries economists will be on familiar ground when analysing the access rights issues. The convergences with recruitment studies deserve a special mention: releasing juveniles before those stages in the life history of a species where density-dependent phenomena affect massively survival rates, or offering extra habitats by artificial reefs after such stages is likely to lead to severe failures. But the well known difficulties in identifying the possible bottlenecks in recruitment processes illustrate how careful anyone must be before announcing an efficient stock enhancement.

The previous remarks will appear trivial to some scientific teams, but it is clear that others seem less prepared to take into account the scientific questions which do not fall directly within their field of expertise, be it aquaculture or descriptive ecology. Multidisciplinary scientific programmes, should take fully into account the available techniques, recognise the difficulties, and when appropriate (often!) analyse previous failures and, as already mentioned, a better dialogue between scientists and the other partners is also necessary. It cannot be an easy task, as demonstrated by the difficulties encountered by stock assessment specialists in convincing fishermen, before a drastic collapse, that a stock is over fished. But all necessary attempts must be developed for a transparent dialogue. This implies: a realistic assessment of the chances of success before a large scale programme is launched, a clear definition of the target(s) of such a programme, and a stubborn insistence on the fact that management measures will remain necessary.

It is obviously impossible to anticipate everything until a large enough programme is developed. But an examination of past experiences reveals that undue optimism has been a too common feature.

The release of juveniles can target on the (re)introduction of a population, in which case the immediate target will be the (re)building of a sufficient spawning biomass. But it can also be a simple extensive aquaculture, where the first aim will be a sufficient recapture. An artificial reef programme can target on the attracting effects, on the protection of an area against trawlers, or an increase through "improved" habitats of the exploitable biomass (in which case the relevant species should be explicit). Too often fishermen are led to believe that the real effect will be the third one, while it is by far the most difficult one to obtain and measure, apart for a few fixed species. The easiest effect will be the protection against trawling, in which case an artificial reef can be a very expensive way for achieving such a target. Announcing clearly what are the expected effects is absolutely necessary for a transparent dialogue. It is also necessary for adapting the scientific monitoring, and the design of the artificial reef.

The previous remarks on the access rights issues demonstrate that the basic management issues will remain relevant even if an enhancement programme is developed. Such a programme should even be compared in a cost/benefit analysis to classical management measures: a decrease in the fishing effort or an increase in the age at first capture will often prove more efficient for increasing the spawning biomass than a restocking plan. On the other hand, if severe over fishing exists, it can also result in a misuse of the "artificial" component of the recruitment, which reinforces the necessity of a better management in the classical sense. In fact, in most cases an enhancement programme is not a substitute to efficient management, but must be part of a management scheme. Quite often it will not lead to benefits for all fishermen, but to some of them, and can even create restrictions for others, for instance those fishing a stock for which an artificial reef will act as a concentrating device while they are not allowed to fish in its vicinity. An enhancement component can also help to make a management scheme more easily acceptable by fishermen. This can be very positive, unless it creates illusions on the possibility of avoiding "restrictive" components such as reductions in fishing effort.

From a management point of view enhancement programmes must not be rejected as a potential tool. But a realistic approach is necessary. Scientifically it implies a very rigorous approach. It cannot be considered as a scientific domain *per se*, and so it cannot be a priority in a research framework programme. But a safe development of future enhancement programmes will require scientific progress related to various topics and disciplines, such as improved methods for the monitoring of fish abundance, the analysis of interactions between fisheries and the environment, the combination of biological and economic approaches. DG XIV will try to back up the necessary methodological improvements, in order to promote better science as well as possible realistic enhancement projects, properly integrated within management strategies.

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Cod enhancement studies - A review

Terje Svåsand

Institute of Marine Research, Div. of Aquaculture, P.O. Box 1870, 5024 Nordnes - Bergen, Norway

Background

In 1864, G.O. Sars raised the question whether the production of cod could be increased by release of artificially hatched cod (Solemdal *et al.* 1984):

> " The question might even be raised, if nature might not be assisted in this respect, so as to prevent the occurrence of unfavourable years, which exercise such a depressing influence not only on those specially engaged in the fisheries, but on the whole country. I here refer to the artificial hatching of fish."

Sars' suggestion of developing methods for hatching cod eggs was taken up by Captain G.M. Dannevig, who founded the Flødevigen Hatchery in 1882, and the production started in 1884. In 1878 hatching of cod eggs was attempted at the Gloucester Station, Mass., USA, and large-scale production started at the Woods Hole Station in 1885 (Solemdal et al 1984).

Releases of artificially hatched yolk sac larvae of Atlantic cod continued for nearly a century, and more than 70 billion(10^9) yolk sac larvae were released in Norway and USA. However, evidence of any beneficial results were not obtained, partly because little effort was made to evaluate the effects of the releases (Shelbourne, 1964; Solemdal et al., 1984). Moreover, it is difficult to distinguish effects of releases from random variations owing to variable recruitment between years (Tveite, 1971).

The possibility for cod enhancement received new enthusiasm in the nineteen-eighties after the breakthrough in cod production in a seawater pond in 1983 (Øiestad *et al.*, 1985). The first release experiment started in September 1983, when more then 20.000 tagged reared cod were released at Austevoll, and two other places in western Norway (Svåsand, 1990a).

In 1985 this research was scaled up when the Norwegian Council of Fisheries Research initiated a cod enhancement programme with projects at the Norwegian Skagerak Coast, western Norway, and in the Tromsø area in northern Norway.

In 1990 this research was further scaled up when the Norwegian government decided to launch a nation-wide enhancement programme with Atlantic cod, and other promising species Atlantic salmon (Anon. 1989), Arctic charr, *Salvelinus alpinus* (Heggberget 1991), and lobster, *Homarus gammarus* (Meeren *et al.* 1990).

In the 1991-93 production and release projets were also initiated in Denmark, Sweden, the Faroe Islands, coordinated by the Nordic Council of Ministers.

This working document gives an overview of the main published results from the cod enhancement programme (most results refer to experiments in Norway). I will concentrated on the following items, which I feels important for a successful result:Production of juveniles for release, tagging, comparative studies, migration, mortality, and carrying capacity and effects of the releases.

Production of cod juveniles for release

In 1983, Norwegian scientists succeeded in mass rearing of juvenile cod (4-6 months old) in a natural seawater pond in western Norway.

In the following I will give a brief overview of this semi-natural production method.

In western Norway the production cycle starts in the end of February, when the cod broodstock are transferred to a spawning pen where the cod spawn naturally. The fertilized eggs are collected from the spawning pen and transferred to the hatchery where they hatch after 2-3 weeks (depending on the temperature). Several million newly hatched cod larvae are then released in large sea-water ponds (size: 30,000 - 500,000 m^3) at densities of about 15-30 larvae/m^3. About five months before the larvae are released, the pond was treated with rotenone (a plant poison) to kill potential predators. From release until metamorphosis (35-45 days after hatching) the larvae feed on natural zooplankton. At the time of metamorphosis, the plankton community in the pond usually is grazed down and zooplankton have to be supplied.

The period from metamorphosis until the cod will accept dry feed at a size of 0.5 gram is very critical and today the mortality in this period is too high. At metamorphosis the number of cod in a pond have been several millions, while the numbers produced (size 10-50 g) have been < 350,000.

The cod are collected from the pond at size of 0.5-2 gram, vaccinated, sorted and transported to netpens outside the pond for ongrowing until time of tagging.

Also other production methods as basin, and large plastic bags have been tried, with varying results. All methods based on natural plankton are influenced by natural fluctuation and the final production results will vary from year to year. Effort are therefore made to optimize the production method, and stabilizing the production potential.

One company in Norway has also tried the intensive rearing method using rotifers and artemia. This may be a future method, but have not yet be a success.

To sum up, it is today possible to produce high quality cod, using semi-extensive methods. However, the methods are unstable, and not cost-effective. This mean that before we can start full-scale enhancement programmes, the production methods must be developed further.

The semi-extensive methods have however produced enough juveniles to conduct extensive enhancement programmes primarily in Norway, but also in Denmark, Sweden and the Faroe Islands, with goals to investigate the potential for cod enhancement.

Tagging

When trying to evaluate effects of releases of fish, efficient tagging methods are necessary. In general, tagging data may contain several intrinsic sources of errors that may influence the results (e.g. Buckley & Blankenship 1990; McFarlane, Wydoski & Prince 1990). These errors may be grouped as: shedding of tags, tagging mortality, tagging artifacts such as growth depression or increased predation risk, and under-reporting of recaptured tagged fish.

External tags

When studying migration and when information from fishers is needed, Floy anchor tags have been used to mark reared fish before release. The cost of the tag (3 NOK a tag) and the laborious tagging process has limited the use of Floy anchor tags to relatively small releases (< 30,000). Floy anchor tags can be used on cod larger than about 15 cm with low tagging mortality but shedding of tags has been a problem (Svåsand 1990). Kristiansen & Svåsand (1990) used an underlying assumption of zero % tagging mortality and 10% shedding of tags.

Growth of untagged wild and tagged reared coastal cod of the same ages were similar, and seldom significantly different (Kristiansen 1987; Svåsand *et al.* 1987; Svåsand et al., 1990, Kristiansen & Svåsand, 1990. This indicates that use of Floy anchor tags has no apparent effect on the growth of coastal cod. Similar results were reported by Jensen (1967) for larger wild cod tagged with Lea and Petersen disc tags in the waters off New England.

The oddity of the prey may increase the predation risk, and Landeau and Terborgh (1986) showed that dyed silvery minnows, *Hybognathus nuchalis*, in schools of undyed fish were eaten more often than their schoolmates. Also, visual tags may increase the oddity of the tagged individuals. However, recapture rates of internally and externally tagged cod of similar sizes were not significantly different (Svåsand *et al.* 1987), indicating no significant effects on survival of external tags on cod. A possible reason for this is the solitary behaviour of 0-group and older cod. Negative effects of external tags might, however, be a larger problem with schooling species.

Another important aspect is under-reporting of recaptured tagged fish. Reporting rates in tagging experiments are often a function of advertising (Holt 1963). The tagging operation should therefore be announced in local newspapers and pamphlets, including registration forms for recording of information on recaptured cod, should be sent to local fishermen and households as done in the experiment reported by Svåsand *et al.*, (1990) in western Norway. Due to the extensive information campaigns and regular communications with local fishermen, Svåsand *et al.*, (1990) used reporting rates as high as 90%. The validity of this assumption was not tested, but can be examined by looking at recapture rates of fish released at larger sizes at the same area. The predation risk for cod larger than about 30 cm is low, and natural mortality has been estimated to about 20% year^{-1} (Svåsand & Kristiamsen 1990b). Between 44 and 52% of larger tagged cod (length > 30 cm) were reported recaptured from releases in the same area (Svåsand 1990). When accounting for 10% under-reporting, shedding of tags (10%) and annual natural mortality of 20% this shows that the assumed reporting rate is reasonable. However, reporting rates may fluctuate, and should therefor be evaluated at each location.

Internal tags

For large scale releases, less expensive and more efficient tagging methods had to be developed. Oral feeding by oxytetracycline turned out to be an efficient mark for mass tagging of cod (Pedersen and Carlsen 1991; Nordeide *et al.* 1992). OTC binds with proteins in the blood and is incorporated in newly formed and mineralizing bone and cartilage and the marks can be visualised using ultraviolet light. The centrum of cod is used for detection of OTC-marked individuals (Pedersen and Carlsen 1991) Pedersen and Carlsen (1991) reported that during a course of a 14 month on-growing period, there were no significant differences in growth and condition between the control group and the OTC-group. In this experiment the marking efficiency was 99%.

In 1988, nearly 82,500 0-group cod marked with oxytetracycline (OTC) were released in Masfjorden (Nordeide *et al.*, 1992). Nordeide *et al.* (1992) found no indications that the OTC affected growth or survival of the cod. The results from this study showed that percentage of marked cod in the control group did not decrease during a period of almost 3 years after marking, although the intensity of the mark gradually declined. Nordeide *et al* (1992) found no indications that the OTC affected growth or survival of the cod.

Alizarin Complexon is an alternative to oxytetracycline as a chemical mark on cod, and laboratory studies has been very promising, especially for early juvenile and older life stages (Blom *et al.*, 1994).

In 1987, a genetic marker for cod was developed by researchers at the Institute of Marine Research (Jørstad *et al.* 1987), and today nearly 150.000 genetically marked cod have been released (Fosså *et al.*, 1992). This mark which is detectable at all life stages is important for both early life stage investigations and in future large scale release programmes with cod (Svåsand *et al.* 1991). Use of genetic markers also makes it possible to test spawning success of released reared fish.

To sum up, we have today developed efficient tagging methods for cod, both for external and internal tags. Today Floy anchor tags is best for the external tag, and there are different sorts of internal tags. There should however be room for improvement, both for the internal, and external tags. New low-cost external tags giving low tag retention should be developed. Northwest Marine Technology, Inc. has recently come up with some interesting new types as Fluorescent Micro-tags and laser tags. This approach should be followed up. Although external tags have several drawbacks, they are necessary, when we want to study migration patterns, tag return rates, and other information from fishers. However, in large scale releases the larger part of the releases would have to be marked with chemical or genetic marks.

Comparative studies

An important question that has to be raised when planning to enhance natural fish populations is whether reared fish are suited for a life in the wild, or more specific, if there are differences between reared and indigenous fish. There are many published examples of observed differences between reared and wild individuals (e.g. see reviews by Blaxter 1975; Browman 1989).

Comparative studies of reared and indigenous cod were also incorporated in the Norwegian cod enhancement program and studies of important population parameters as growth, survival, feeding, and migration have been conducted. An overview of published results reveals only minor differences:

Genetics
Genetic investigations were incorporated in the cod enhancement experiment in western Norway. At one of the release areas, studies of allele frequencies in 4 loci (Hbl, LDH-3, PGM and PGI-1) were conducted (Svåsand *et al.* 1990). Two rare alleles, *PGM(150)* and *PGM(70)*, found in the wild population turned out to be lacking in the broodstock consisting of 74 mature cod caught in the release area. No other genetic differences were detected, neither between broodstock and offspring, nor during a period of three years after release. The loss of the two rare alleles shows that the number of cod in the broodstock was too low and a higher number of spawners should therefore be used to produce juveniles for future release experiments.

Similar conclusions were also found in the large scale enhancement programme conducted in Masfjorden, western Norway (Jørstad *et al.*, 1994)

Growth
Several authors have reported similar growth of reared and wild cod in the same area (Moksness and Øiestad 1984; Svåsand & Kristiansen 1985; Kristiansen 1987, Svåsand, Kristiansen & Næss 1987; Svåsand *et al.* 1990, Nordeide 1993, and others).

Feeding and behaviour
Released cod had learned to catch the same prey types in the same proportions as the wild cod the second week after release, but the mean weight of stomach contents and the mean numbers of prey per stomach were smaller, and a larger proportion of the newly released fish had empty stomachs (Kristiansen and Svåsand 1992). Similar feeding preferences (Svåsand and Kristiansen 1985; Kristiansen 1987) and weight of the stomach contents between wild and reared cod (Kristiansen 1987) have been reported, based on stomach content analyses of I+ cod. However, Nordeide and Salvanes (1991) found differences in feeding behaviour between wild and newly released reared 0-group cod. This indicates that reared fish need some time after release to acclimatize to the new environment. Also with regard to predation, Nordeide and Salvanes (1991) found that densely stocked 0-group cod were heavily preyed upon just after release, and Nordeide and Svåsand (1990) reported differences in behaviour of juvenile reared and wild cod towards a potential predator. The first period after transition from the production unit to the release area might, therefore, be critical.

Migration
Svåsand (1990b) tagged wild and recaptured cod of same size classes and released them in the same areas. The result from this experiment shows a similar and not-significant difference in displacement between recapture areas for wild and reared cod. However, there is found some indications of different small scale migration in the first period after release. This, has

to be studied further using radio tracking.

These differences are, however, small compared to what is reported for other species. What may be the reason for this? One is obvious; the released cod were produced in a semi-natural production system (Øiestad *et al.* 1985) and were startfed on the same naturally occurring zooplankton, as wild cod are. The reared cod fed on natural zooplankton from startfeeding to past metamorphosis, and were only offered artificial feed from about one month past metamorphosis. The production pond has also many similarities with the natural environment with regard to predators and vegetation. Most other species used for enhancement purposes are produced in smaller artificial systems, and they are usually only offered artificial feed. In addition, the production environment is often tanks with little or no resemblance to the natural environment.

Browman (1989) focused on critical periods and suggested that spatial and temporal overlap between the developing organism and specific environmental input is essential. From this viewpoint, the production environment should be as natural as possible to ensure that the fish get the necessary stimulus at the right time (critical window). All rearing of fish will to some extent be artificial, but application of a semi-natural production regime and the use of live prey may be an important explanation to why successful results were obtained in these cod release experiments (Svåsand 1993).

To summarize, none of the observed differences between reared and wild cod is critical for a further development of the cod enhancement programme. On the other hand, it is important not to ignore these observations, and necessary precautions (e.g. use of larger spawning stocks) and training of reared cod prior to release should be tried out. Especially, development of methods giving a more rapid acclimatization to and dispersal within the release environment should be investigated in future enhancement programmes. Thus, effect of training is supported by several authors. Learning is suggested as an important mechanism providing behavioural flexibility (Dill 1983), and may increase the ability to avoid predators in salmonids (Patten 1977; Olla and Davis 1989). Moreover, it has been shown in a study with European minnow, *Phoxinus phoxinus*, that anti-predator behaviour is inherited, but modified by early experience (Magurran 1990).

Migration

Migration patterns of released reared fish are discussed in a separate working document.

Natural mortality

Mortality after release have been estimated in western Norway (Svåsand and Kristiansen 1990b; Salvanes and Ultang 1992). Decreased mortality with size is well documented for marine species (Peterson and Wroblewski 1984; Folkvord and Hunter 1986; Anderson 1988; Tsukamoto *et al.* 1989; and others). Likewise, increased survival with increased size at release for 0&1-group cod (mean lengths: 16-22 cm) are reported by Svåsand and Kristiansen

(1990b). Moreover, natural mortality seems to stabilize at the end of the 1-group stage, and instantaneous coefficient of natural mortality of cod larger than about 30 cm was estimated to 0.22 year $^{-1}$ (Svåsand and Kristiansen 1990b). The most probable reasons for pre-recruit (0&1-groups) mortality in the investigated locations in western Norway are cannibalism and predation from pollack. As the cod grow in size the risk of predation will decrease. This suggests that size at release and time spent to grow trough the predation phase probably affect the survival of released cod, and may explain the observed size-dependent mortality.

For earlier life stages of coastal cod, no survival data has up to now been available, primarily due to problems with effective tagging methods for cod smaller than 10-15 cm (Svåsand 1990).

For all age stages, methodical problems have limited the possibility for accurate estimation of mortality rates.

Carrying capacity and Effects of releases of reared cod

An ecosystem model describing the carrying capacity for cod has been developed for Masfjorden, north of Bergen (Giske *et al.* 1991; Salvanes *et al.*, 1992). The results from the model shows that the carrying capacity for production of cod is sensitive to advection of zooplankton to the fjord, and the availability of benthic preys. Since the advection rate of zooplankton to the fjord varies between years, the carrying capacity is dynamic and varies between years.

According to the authors the following conclusion can be drawn:

1. Optimal cod production can be obtained if the sum of released and wild recruits is within the range of carrying capacity of juveniles

and,

2 Releases of the same number of juveniles in several years will result in dissimilar cod production due to interannual variations in zooplankton availability.

For a more detailed discussion, see working paper by Jarl Giske.

Field studies also confirm this model (Nordeide 1993): Between 1988-1990 more than 170.000 tagged cod were released in Masfjorden. They were 4 to 7 months old at the time of release. As early 1-group, the three manipulated yearclasses consisted of more than 40% reared individuals. Due to the releases the abundance of cod was higher in the release area compared to the control area were no cod was released. However, at the 2-group stage the abundances of cod in the release area were not significant different from the control area. The decrease in abundance in the release area compared to the control area might be explained by density-dependent mortality, caused by lack of food.

Only minor effects are reported on wild cod or other species, as result of the releases.

Nordeide (1993) conclude that:

- High food abundance, giving fast growth (and high condition-, and liver-index) during the first 1 3/4 year, seem to be required to produce a strong year-class in a fjord like Masfjorden.

- Release of reared cod may not necessarily give any measurable increased production of cod in the fjord.

Summary and future prospects

- The production of juveniles for release are unstable and too expensive

- The pond reared juveniles are suited for release

- Only minor differences between reared and wild cod are reported

- Cod released in sheltered coastal and fjord areas will remain in the release area (some exceptions are reported)

- Investigations have revealed density-dependent mortality in fjord areas, probably caused by limited food resources to sustain an increased cod population

The areas were artificially cod have been released consists of a variety of ocean, fjords and coastal areas with varying hydrographic conditions. Attributed to differences in sill depths and other topographical parameters, different fjord ecosystems exhibit large variations both within and between regions (Lie 1985). One might therefore question how far it is possible to generalize the results obtained in one area. Furthermore, results from the cod enhancement programme show conformity between areas in some parameters but dissimilarity in others. This suggests that several of the results put forward from western Norway might not be valid for other regions without further investigations. Nevertheless, the conclusions will be important as hypotheses for such investigations.

However, even if the conclusion of this research should be that it is possible to increase the output from the inshore cod fisheries through releases of reared cod, some important questions remain to be answered before this kind of extensive aquaculture can be a reality. A full scale enhancement programme will demand a continuous supply of low cost cod fry. Today, this seems to be a problem, but great effort is put into optimizing the rearing techniques (e.g. Blom *et al.* 1991). Legal aspects involving ownership of the released fish will have to be solved (Ørebech 1988), and a final question will be whether a cod enhancement programme will be economically feasible (Sandberg 1988; Sandberg and Flåm 1988).

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BALTIC COD: NATURAL DEVELOPMENT AND POSSIBLE ENHANCEMENT

by Fritz Thurow
Langensaeten 12, D - 24 226 Heikendorf, Germany

Abstract:

Is there a bottleneck which could prevent enhancement measures to be successful ? Abiotic conditions, nutrients, predators, and the availability of food may play a rôle in this respect.

The influx of Atlantic water into the Baltic Sea is of paramount importance for the area. Cod needs a salinity of over 10 ‰, and O_2 of more than 2 ml/l for the eggs to develop. The overall trend during the first 50 years of this century was an increase in salinity in the bottom water layers and a decrease subsequent to that. Increasing amounts of nutrients were stored there which reduced the oxygen content. A clear rise of nutrients in surface layers was observed since the second half of the 1960's. As a consequence, primary, and zooplankton production increased 1.3 fold. Fish production more than doubled, biomass rose manyfold.

The gains in fish production and biomass are partly due to a reduction of seal, and porpoise populations. They declined from some 320 000 by the beginning of this century to some 10 000 at present. Their original consumption amounted to over 300 000 tonnes of fish, three times the landings of the fishery then.

Consumption of cod eggs by clupeids may be of importance for the success of recruitment. Cannibalism does also play a rôle, so that a spawning stock biomass of some 550 000 tonnes produces the highest number of recruits.

Cod larvae feed on zooplankton. After metamorphosis the juveniles turn to bottom animals. From age 2 onward cod increasingly switches over to clupeids. There would appear to be no limitation of cod production from the food side at present.

The Baltic has changed from an oligotrophic to a highly eutrophic sea because of human activity. If we are to reduce the nutrient load and the toxic substances associated with it, fish production must decrease. All this would affect stocking measures very little. The remaining problem would be of an economic nature.

I do, however, feel uneasy about any human intervention with nature. In the past, such engagements have carefully been planned by few people, experts who foresaw everything except human behaviour in particular reactions of groups of people of different interests and great inertia. Removal of unforeseen, adverse effects would also have to be initiated by few people, politicians and administrators. They have shown to be not in a position to be successful. The one possibility I see is probing. If action is found to be indispensible, it should be started on a very small scale. Enlargement would be stepwise when no harmful effects can be shown. This would also apply to stocking, which changes balances in the ecosystem.

1. PROBLEM

When we consider enhancement possibilities to maintain, or increase the size of the cod stock, we do first ask ourselves, do natural conditions permit an interference from outside. At which stage or stages, in the development, is the number of offspring fixed ? In other words, what is the bottleneck for the recruitment, and does it prevent enhancement measures to be succesful ?

2. BOTTLENECKS COD HAS TO PASS

2.1 Hydrography

The Baltic Sea is an ecological system highly dependent on changing environmental conditions. The surplus water production leads to an outgoing freshwater current on the surface and from stability reasons to an ingoing saline current on the bottom. This produces a halocline in the middlewater.

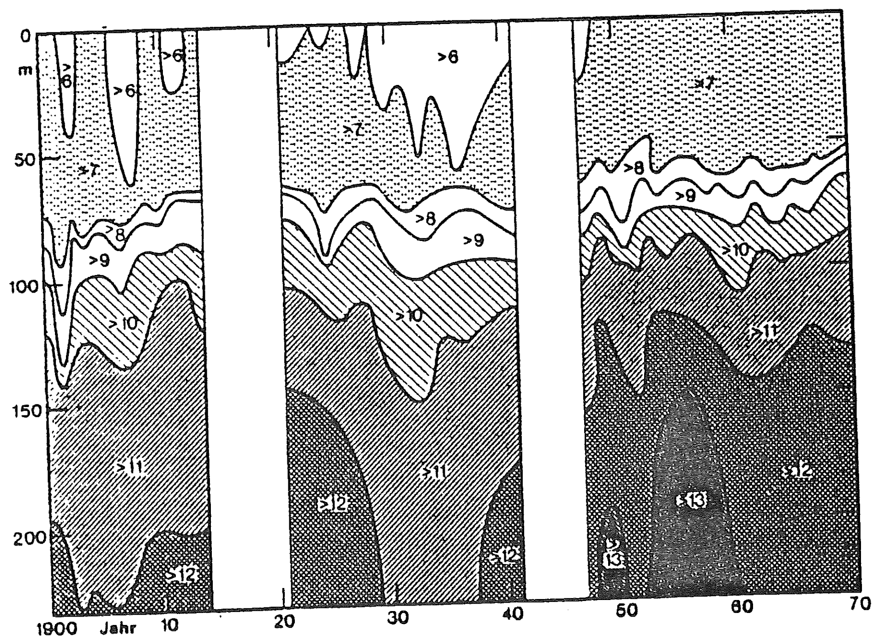

Figure 1: Distribution of salinity in the Gotland deep (Fonselius,1968)

Occasionally strong inflows of saline water occur which change the system quite considerably. Figure 1 shows this process in the Gotland deep for the last century according to Fonselius (1968). During the first 20 years or so the salt masses increased which lifted the halocline by more than 10m. Additional freshwater was added in the thirties which resulted in a downward trend of the halocline. Following this more salt was added and the halocline rose by some further 10 m. Figure 2 splits this overall event into large singular inflows and shows the resulting bottom water salinity.

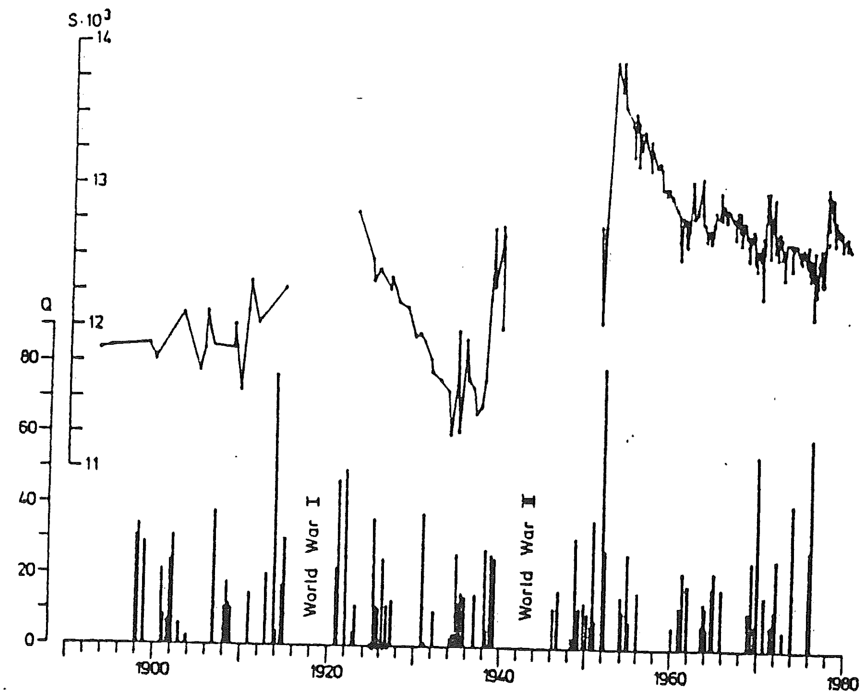

Figure 2: Major inflows (Q) and salinity in the bottom water layers of the Gotland deep (Franck et al.,1987)

The ingoing water coming from the good airated Kattegat carries oxygen along to the Baltic basins. Occasional analyses made between 1900 and 1950 do not show this effect (Figure 3, Fonselius,1968). More frequent sampling since 1958 make the inluence of invasions of Atlantic water obvious, however (Figure 4, Nehring et al.,1984).

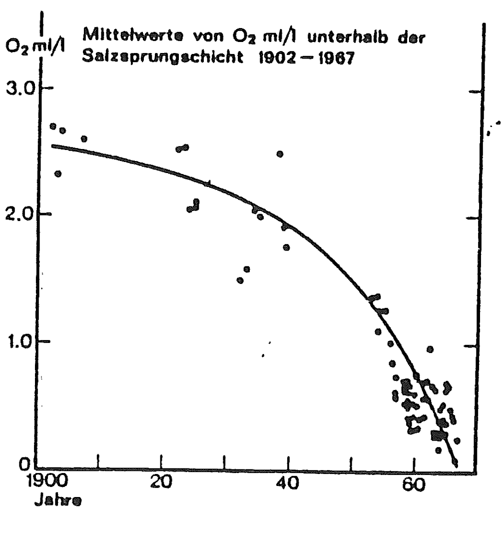

Figure 3: Oxygen content below the halocline,Landsort deep, acc.to Fonselius,1968

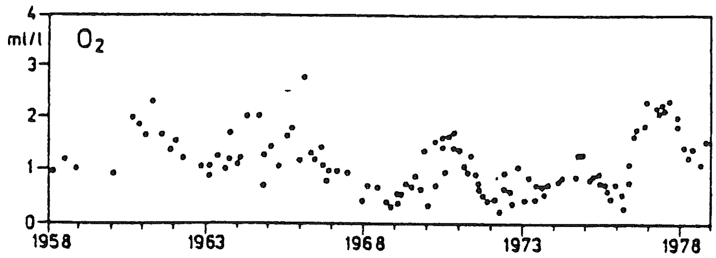

Figure 4: O_2 beneath the halocline in the Gotland deep,Nehring et al.,1984

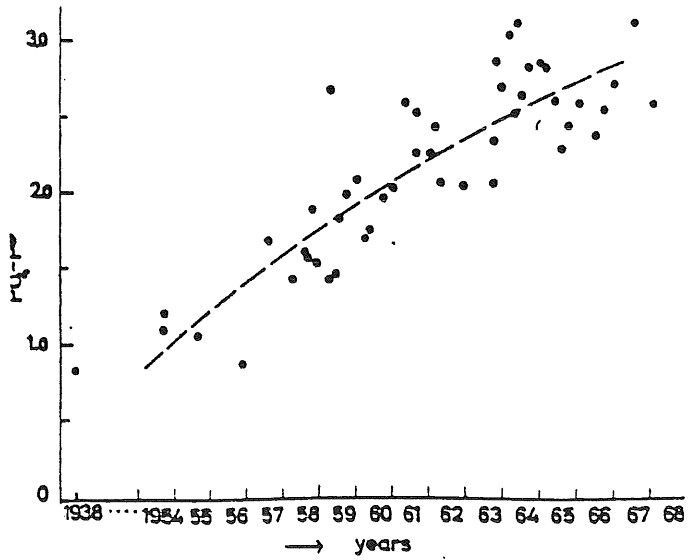

Figure 5: Mean phosphate content beneath the halocline,Landsort deep (Fonselius,1968)

Phosphate has regularily been sampled since the fifties, nitrate since the seventies. Figures 5 (Fonselius,1968), 6 (Elmgren,1989), 7 (Milewska,1982) show a steady increase of phosphate in bottom water layers of the Bornholm,Gdansk, and Gotland deeps in the sixties. In the fifties, and in 1938,and 1947 the values appear to have been low. Between about 1965 and 1983 the contents fluctuated at the higher level. Nutrients in the surface layers behaved differently (Nehring,et al.1984). The enormous increase there started only in the late sixties. It is correlated with a correspoonding increase in salinity. This led Nehring et al.(1984) to conclude that the nutrients accumulated in deep waters were brought to the surface by an upward transport.

2.2 Spawning success

Berner et al.(1989) have investigated the effect of various variables on the number of recruits in the Bornholm, as well as in the Gotland basin

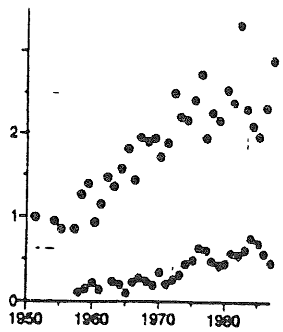

Figure 6: Phosphate in the surface water in winter (below) and at 100m depth as annual mean (above), Gotland deep (Elmgren,1989)

for the period 1969-1983. These variables were Oxygen content as well as salinity in March, May, and August, zooplankton biomass in May, and August, and spawning stock biomass. The analyses were made with simple, multiple, and polynomial regressions. Oxygen in March played the overwhelming predictive rôle for the recruitment of cod in the Baltic proper. The other variables, zooplankton included, kept a minor position.

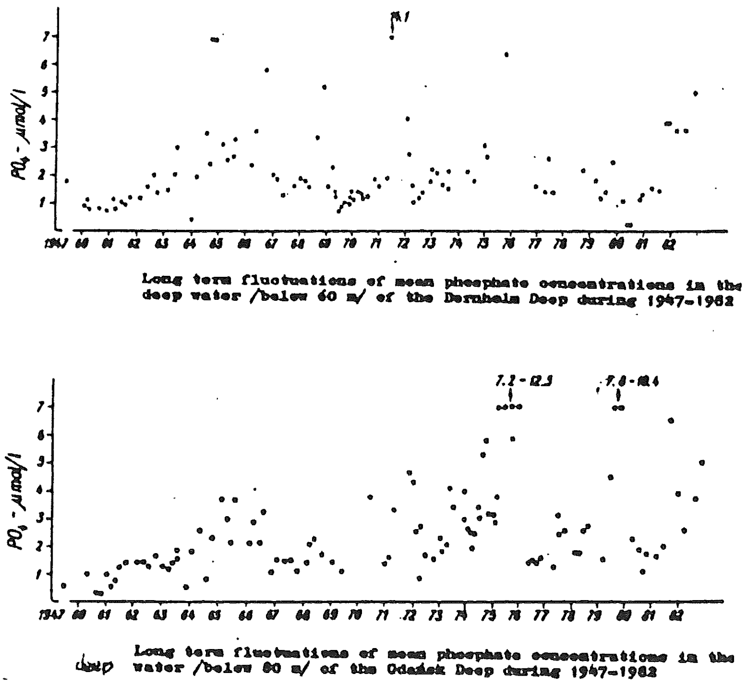

Figure 7: Phosphate content (Milewska et al.,1982

Kosior & Netzel (1989) made simple regressions for the same period. They suggested that oxygen was important for all spawning areas (Bornholm, Gdansk, Gotland). Salinity was also essential for the Gotland, and Gdansk basins, but less so for the Bornholm deep. Parent stock and amount of zooplankton did hardly contribute.

Lablaika et al. (1989) used salinity, oxygen, and water temperature in February and May in the Gotland basin as well as spawning stock size to predict recruitment of two year-old cod for the period 1966-1985. They have not been able to show that one of these factors alone had the sole responsibility for recruitment changes. All of them together, however, did significantly predict recruit numbers. The obvious discrepancy as compared to the foregoing results might be explained by these authors investigating the Gotland basin alone.

Bagge (1993), with unpublished data of Wieland (1993), related year class strength to a factor combined of temperature, salinity, and oxygen content, expressed as the level (m) of water over which certain limits of these variabled were kept. Significant regressions were obtained. But the results showed that optimal levels of abiotic factors do not neccesarily ensure good year classes. Additional unknown variable(s) do act.

A similar method was applied by Carberg&Sjöberg (1992). They correlated the volume of water suitable for spawning and egg development with the corresponding number of recruits. A weak relationship was established.But the authors found suitable conditions for a number of years which did not produce the adequate recruitment. The conclusion was that unknown factor(s) exert(s) important effect(s).

In the above researches the authors have correlated the number of recruits at ages 1 or 2 as estimated by VPA to the variables. The main factors were acting at spawning places during spawning time. The correlation is therefore likely to have been with the spawning success rather than with the number of cod recruiting to the fishery. What happened after hatching was probably of lesser importance,i.e., any mortality after hatching was almost always of the same proportion. This is in contrast to the natural mortality, M2, estimated for younger ages of cod (Jensen&Sparholt,1992) which varied quite a bit 1977-1990. The means of M2 were 0.64 (age 0), 0.34 (age 1), 0.08 (age 2). Predation mortality was of no importance for older cod. However, the stock size of cod increased considerably in the late 1970's but declined subsequently, and so did predation by cod. M2 varied 0.2-1.0 for age 0; 0.1-0.6 for age 1. This might have had quite an effect on recruitment to the fishery. Cannibalism could therefore be considered as one of the "additional factors" mentioned above.

Sparholt (1994) in a preliminary investigation found that a spawning stock biomass of 550 000 tonnes (cod in the central Baltic) gave the highest number of 3-group cod. Since cod of this age make the most important contribution to the fishery, SSB of 550 000 tonnes may be considered to be optimal. Sparholt discovered furthermore that a change in the relationship between recruitment and biomass, i.e., other environmental conditions which modified the survival of recruits did not change the spawning stock biomass producing the highest number of 3-group cod. The carrying capacity of cod spawners may therefore be considered to be 550 000 tonnes. This means at the same time that cultured cod added to the natural production in addition to a SSB of 550 000 tonnes would be in vain.

2.3 Food of cod

Cod larvae, in their pelagic stage, sustain on zooplankton. The above investigations do not give the slightest idea of a food shortage in this stage. In fact, the clupeids largely depend on this food throughout their life. It can, however, not be excluded that the clupeids as well as the cod larvae may at times be delimited by the availability of zooplankton.

Once the young cod turn to the demersal life, they start to feed on bottom organisms, in particular invertebrates. Among them, Mesidothea entomon is becoming of increasing importance from age 1 onwards. At an age of some two years cod switches over to a fish diet for the first half of the year. They are likely forced to do so because most of them stay in the spawning shoals on or over deep waters where the bottom layers may be devasted of oxygen. Clupeids then and later are the main diet. In the second half of the year, when the three, and four year olds return to the shallow waters, they do again feed on invertertebrates . The oldest fish stick to fish diet then (Spahrholt,1993). Figure 8 shows the consumption of clupeids by cod as analysed by the Multispecies Assessment Working Group.

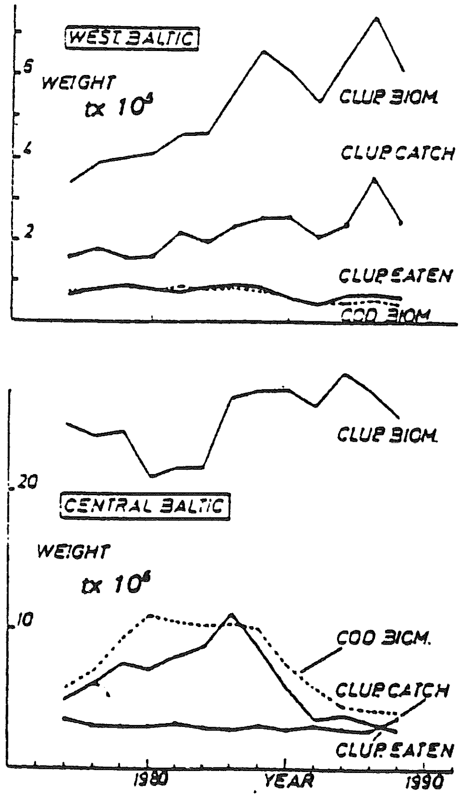

Figure 8: Amount of clupeids eaten by cod (Anon.1990)

Large bottom areas of the central Baltic are devasted of bottom living animals. Throughout much of the year these regions suffer from anoxic conditions. Above the halocline, however, where sufficient oxygen is available the year round, the biomass of bottom fauna has increased manyfold during the last decades (Elmgren,1989). There would thus appear to be no limitation of cod production from the food side at present.

2.4 Predation on cod

Clupeids prey on cod eggs, cod itself eats younger individuals of its species, and seals are predators of cod as well.

Predation of clupeids on cod larvae seem to be of no importance but their egg consumption appears to be more substantial (Köster,1992). the main stress is on eggs in the beginning of the spawning season (March,April) when the zooplankton production is low. The total cod egg consumption by sprat is said to be higher than by herring.

Cannibalism was mentioned towards the end of section 2.2. The question whether or not cannibalism is significantly contributing to the fixing of recruit number remains to be answered.

Mammals in particular seals consumed great amounts of fish during the first decades of this century (Elmgren,1989). The breakdown of their diet to fish species in the early years is not well known. According to present investigations, however, cod is eaten by all species although little by the ringed seal(Pusa hispida) (Almkvist et al.1980). At the present low abundance of seals, they do not affect recruitment and stock size of cod.

3. PAST CHANGES IN BIOMASS

One of the remarkable features of this word is, however, that nothing remains unchanged. We might therefore want to have a look at the past to see whether the present situation has prevailed over long periods or if there have been any remarkable fluctuation in stock size.

3.1 Method

Biomass is estimated for each age by use of $Y/F = B$. The yield,Y; is available from statistical yearbooks. The fishing mortality, F, has been evaluated by subtracting natural mortalities used by Assessment Working Groups from Z at age. Z itself was found semigraphically from age composition of catches. From the above equation, $F = Y/B$ is the fishing mortality at age. The fishing mortality over all age was therefore calculated as a weighed average weighed by the biomass of each age group.

The values of Y/F estimated thus had to be calibrated against known biomasses for the periods since 1970 when biomass has been assessed by means of VPA. This procedure gave average biomasses for periods with C.L.s shown in the following figures.

3.2 Biomasses

The total biomass of all fish species in the Baltic (million tonnes) is dipicted in Figure 9. Confidence limits are shown for periods of 10 years. These and their means are the original assessments. From an interpolation of the mortalities the basis for annual estimations was achieved. Shortterm fluctuations are obvious for the years from 1970 onward for which biomass is largely evaluated by the Assessment Working Groups. These variations do not come about by the present method. For the twenties, the forties and the late sixties, the upper limits are shown to be infinite. This is largely due to too few values for some of the periods of herring assessments in the Belt Sea. These infinite values are then carried on to the total of herring and to the total of all species. If, for instance, the degrees of freedom are set at three instead of two, the upper limits are down to normal as indicated by the lines of crosses.

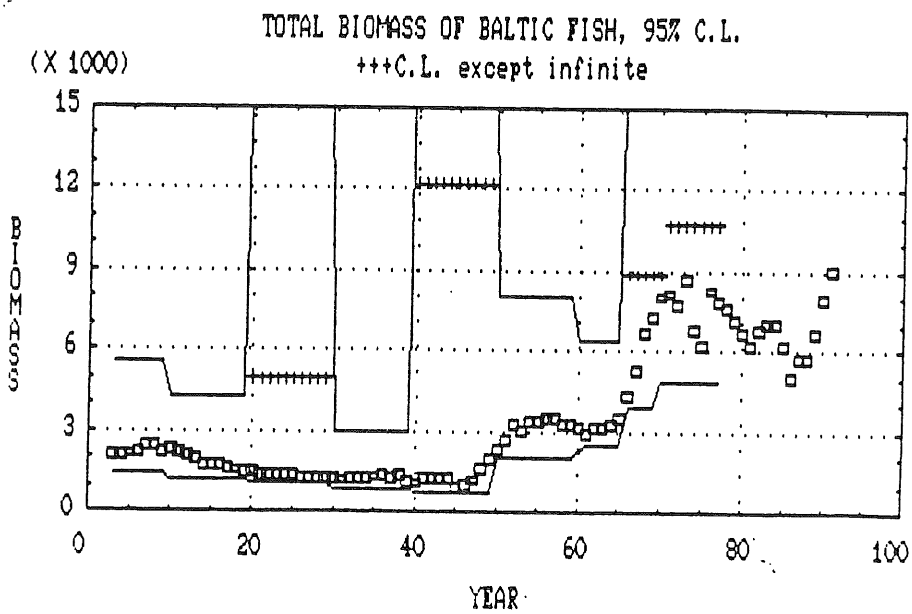

Figure 9: Total Biomass of Baltic fish

At any rate, the means for periods as well as the interpolated values suggest that total biomass started off by some 3 million tonnes. During the following decades it fell to less than 2 million tonnes. Only in the forties when the seal populations have been reduced from over 300 000 to about one tenth this amount, did biomass grow. It reached a level of almost 4 million tonnes in the fifties. A second enormous rise occurred in the second half of the sixties so that almost 9 million tonnes were present by the beginning of the seventies. Let us now look at a breakdown to the most important species, sprat, herring, and cod.

Apparently, sprat kept a very low biomass throughout much of this century until about 1950 (Figure 10). This was followed by a gain which was very steep in the second half of the sixties. These estimations are compared with Polish catch rates (blocks) for the period 1945-1960, which show the same increasing trend since the middle of the fifties as the present evaluations (Lasczynski,1964). In addition, results obtained by Rechlin

(1975) exhibit the same tendency as shown in Figure 9 (crosses). These supplementary results suggest that the present estimations may be correct.

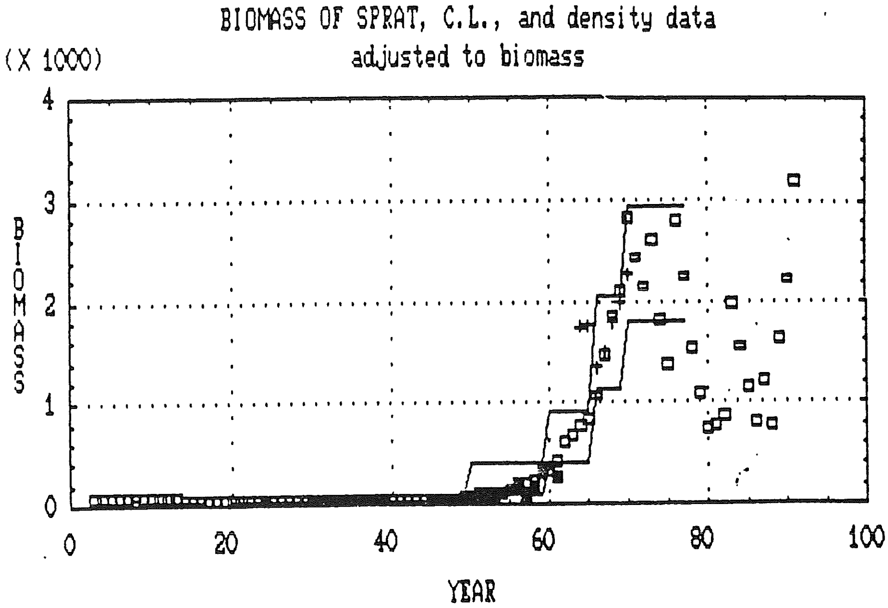

Figure 10: Biomass of Sprat in the Baltic

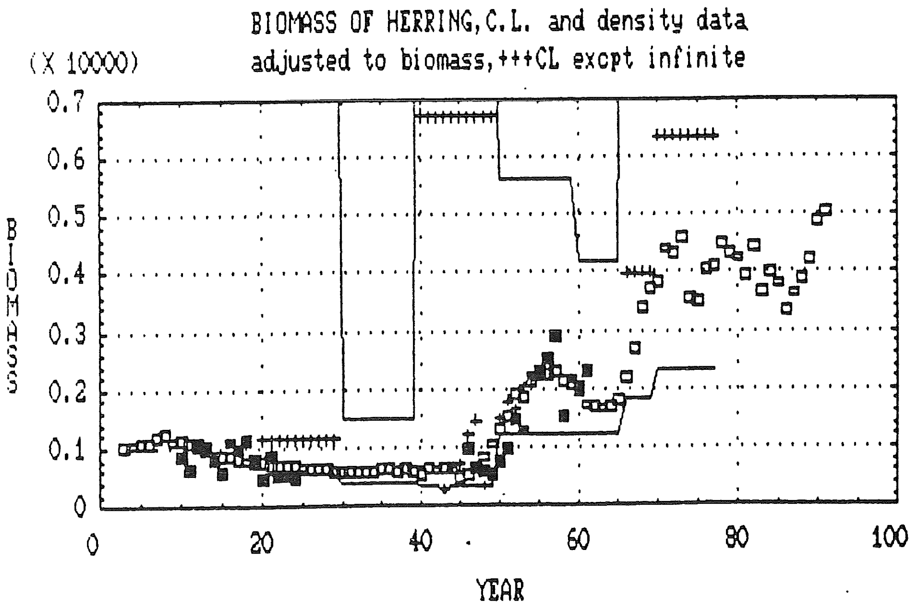

Figure 11: Biomass of Herring in the Baltic

The development for herring is depicted in Figure 11. On a smaller scale, this repeats what was shown for the total fish biomass because herring contributes some 50% to the total biomass. The investigations are also accompanied by series of catch rates. Jensens (1948) data cover the period 1911-1924, and they suggest a declining trend. The data of Sahlin (1959) refer to 1943-1955 (crosses). Apart from two high values in 1946 and 1947, they show an enormous increase in the fifties. The long series of Laszcynski (1964) reports for 1945-1960. An immense gain until 1956 and a subsequent fall is obvious. Hence, both series indicate the same trend as the present investigations.

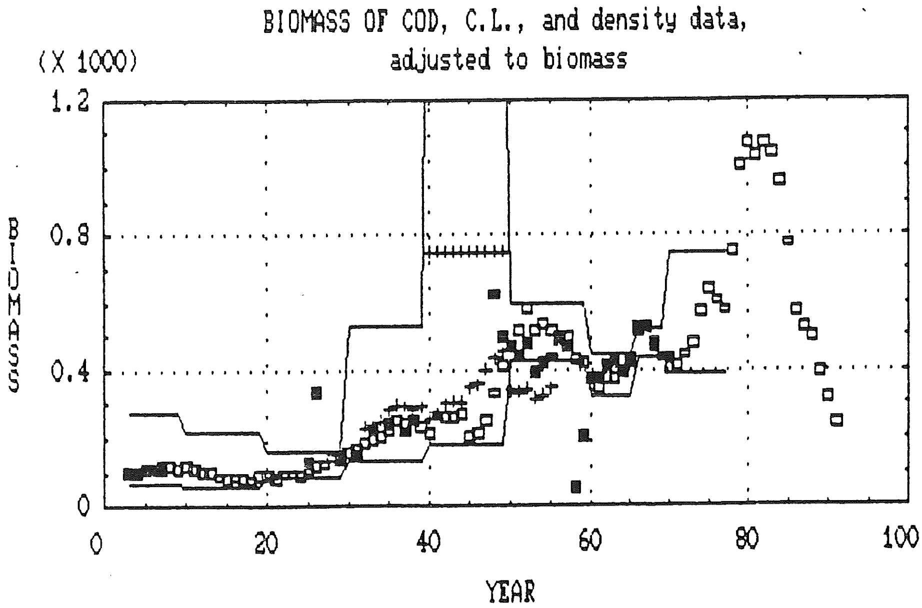

Figure 12: Biomass of Cod in the Baltic

Figure 12, finally, shows the development of the biomass of cod. In contrast to the clupeids, the first increase starts some 20 years ealier, namely in the twenties. A second rise is obvious in the forties. This ends up in a maximum in the beginning of the fifties and a second one in the middle of the sixties. After a final steep rise in the seventies the climax is reached by about 1980. Several catch rate series support the trends of this development. The data of Kändler (1944,1948) extend over 1903-1938 (blocks). With an exception for 1926, they nicely follow the same trend as the present evaluations. Sahlin (1959) has collected information for 1932-1955 (crosses). Until about 1950 they fully match the results in question but not so for the remaining years. In the same way, catch rates of Dementjeva (1959) collected for 1948-1956 show a minimum in the beginning of the fifties when the present results indicate a maximum. For 1960-1969, finally VPAs of Kosior (1975), Berner&Borrmann (1980) enable the last set which again is in good conformity with the estimations at issue.

4. CONCLUSIONS

The three most important species are shown together in Figure 13. Cod is the only species critically dependening on appropriate density, and oxygen conditions of the water.- Figure 2 indicates that salinity in the bottom layers, increased quite considerably until 1953 when at the same time cod biomass increased from some 100 000 tonnes to over 500 000 tonnes. During the next 30 years salinity dropped and cod kept its biomass at the same level. At the end of the seventies a number of good year-classes hatched which subsequently doubled biomass to about 1 million tonnes.

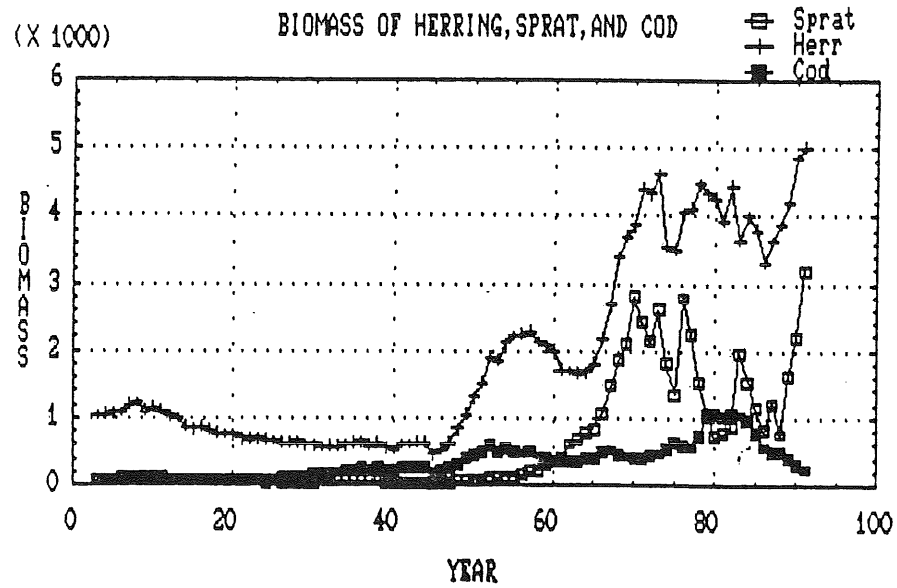

Figure 13: Biomass of herring(crosses),sprat(boxes),cod(blocks)

There seem to be no doubt that the change of the Baltic ecosystem from an oligotrophic to a highly eutrophic water was largely caused by human pollution. During this century the nitrogen input increased up to fourfold, phosphorus manyfold (Brüggemann,1993,p.6). The optimum spawning stock biomass was estimated at some 550 000 tonnes under recent conditions. If we we will be successful in reducing the nutrient load and the toxic substances associated with it, fish (and cod,) production must decrease. A total biomass of some 500 000 tonnes which has prevailed undisturbed for about 30 years is more realistic and possibly even less than that. This would correspond to a spawning stock biomass Of roughly 400 000 tonnes.

All this would affect enhancement measures very little if cod were to be released. The remaining problems would be of economic nature. To reduce management costs, one would tend to release cod at younger ages. This could be more promising. The thing would be much cheeper. With some experience, losses could be kept to a minimum.

With regard to economic criteria we do have examples with salmon, in particular in the Baltic Sea. Sweden considered that power station building in Swedish rivers distroyed the possibility for natural propagation. It therefore released a law according to which any reduction in propagation potential by power stations had to be replaced by artificial salmon production. This is the overriding criterion still applied. However, salmon exploitation in the Baltic as elsewhere used to be on the coast and in rivers particularily. This changed after 1945 when the open seas fishery with long lines was introduced by countries other than Sweden. There have therefore been attempts by the Swedish side to have these other countries participate in the efforts of salmon enhancement measures. The new criterion tentatively established then was the value of the catch of feeding salmon per Swedish Krona used for enhancement. This would be the total international catch or alternatively the Swedish catch of salmon. The first limit set would be that the above value would have to be > 1. In other words, if the value were to be ≤ 1, the money could better be directly paid to the fishermen.

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Lobster stock enhancement in Norway

Gro I. van der Meeren
Austevoll Aquaculture Research Station
N-5392 Storebø, Norway

Abstract

In 1988 the Institute of Marine Research commenced a pilot scale release of marked, one year old juvenile lobsters, *Homarus gammarus*. In 1990, a large scale release project commenced. Releases has been arranged yearly through to 1994 at Kvitsøy, an island community in Southwestern Norway. In this project juveniles were tagged with magnetic (Bergman-Jefferts) microtags. The juveniles were then released in large numbers, 15-30 000 in each release. Between 1991 and 1993, experimental releases with 500-5 000 lobsters were done in another locality to test different factors like habitat, release density, successive releases and predation pressure.
The pilot project resulted in new knowledge about the Norwegian surface-release technique. The large scale project is continuing with monitoring of the recoveries. The recoveries are registered from the catches in the commercial and spare-time fishery in the release area, in cooperation with the local Fishermen Organization and the community administration. The first recovery in the ordinary fishery was in 1992. Tagged and released lobsters constitute for about 40 % of the Kvitsøy lobster stock under legal size in 1993.

Introduction

Norway, being situated at the northern border of the European lobsters range, seems to have vulnerable lobster populations. The Norwegian lobster stock is at the moment very almost depleted, and has been so for more than twenty years. From catches above 500 tons in the fifties, the yearly catch is now about 30 tons. Release has been considered as a method both to strengthen the stock and as a viable sea ranching industry. Lobster juveniles has been releases untagged for more than 100 years in Norway (Sund, 1915; Dannevig, 1928). Both private persons and industrial interests have been involved. The largest lobster hatchery in the world has been build by commercial interests (Timar ltd.) in 1981 (Grimsen *et al.*, 1987). No systematic monitoring has been undertaken due to lack of tags in the released animals. In addition sporadic research has been done on the ecology of the adult lobster. It has been no previous research on the life and basic needs of juvenile lobsters in Norway.

When the research on lobster releases was started up by the Institute of Marine Research in 1988, information was received from the UK trials. Still, both the scale of the Norwegian project and environmental and geographical differences are reasons to be cautious in applying UK results in Norway. The Norwegian projects aim to test if releases of intensively produced lobsters can enhance a depleted stock, and the results shall be used to evaluate if releases can be a part of commercial viable sea ranching. The project is financially supported by the national research program "Program for Development and Encouragement of Sea Ranching - PUSH", commenced 1990.

Methods

Hatchery and microtagging

The lobster juveniles were produced from a broodstock caught in the same area as the releases. Juvenile production was situated to the commercially build lobster hatchery, described in Grimsen *et al.*(1987), and overtaken by the Institute of Marine Research in 1989. The production is described in Grimsen *et al.* (1987), except that both the larvae and juveniles was fed frozen *Artemia*. Since 1990, shellsand has been provided in the juvenile boxes to allow development of crusher claw in the juveniles.

Microtagging with "Bergmann-Jefferts" tags was modified, but comparable to the UK. method (Wickins *et al.* 1986). Every release batch were given separate binary code. In the experimental releases tests and control batches had different binary code.

Releases

The Norwegian release sites are illustrated in fig. 1.

All transportation of juveniles were done in thermal transportation boxes, filled with wet newspapers and cooled with a top layer of deep-frozen papers (van der Meeren 1991a). The transportation boxes were sent by car or by air to the release area, were the juveniles were "sown"in shallow water (2-5 m) from small boats, following the coastline. In August 1988, 9 800 one and two year old lobsters were released directly from the transportation boxes by divers. Since then, transported juveniles has been given 30 min, in tanks filled with ambient sea water, to acclimatize (van der Meeren, 1991b). Releases in summer and autumn has been ommited. Most releases has been undertaken in March and April (Tab. Ia and Ib). The first large scale release was in 1990 (van der Meeren *et al.*, 1990).

The first experimental release was in 1991. In this part of the project release through a water-fed tube has been used in addition to the surface release.

Monitoring

No systematic monitoring of the lobster fishery was conducted from the pilot scale release, but target fishing were undertaken in 1990 and 1991.

In the large scale release a thorough quayside screening started in 1991 and is continuing, in close cooperation with the local fishermen and the community administration. Both undersized lobsters and legal ones are length measured. All lobsters are tested for tags, mainly with the "wand", a light field magnetometer, making an audible sound when passed over a tag. Capture-site is noted. In addition the research team from the Institute of Marine Research, the Kvitsøy Community employs one person to do the monitoring during the fishing season. This person stay in close contact both to commercial fishermen and those fishing for leisure and private use. Every reported tag in legal sized lobsters are rewarded with money (appr. 2,5 £), or specially made lobster pins or caps. The tagged lobster is bought by the Institute of Marine Research for further analysis and tag retention. All lobsters captured through the season are measured and sexed. Undersized lobsters are measured, given an external mark or tag and released in the same area as captured.

In the experimental releases, monitoring is done by divers and target fishing by the Institute of Marine Research.

Genetic analysis is done for the lobster broodstock, the released juveniles, the recapture and a sample of wild lobsters, to test for anomality in the produced and released lobsters.

Results

In the pilot scale release, the mortality due to predators raised to more than 10 % within the first hour (van der Meeren, 1991a). The control group had less than 2% mortality the first week. The reason for this was the apathetic or spastic behaviour shown by the juveniles. The low temperature in the transportation boxes was the cause for the abnorm behaviour traits (van der Meeren, 1991a). Further laboratory experiments showed that a 30 min acclimatization in natural tempered seawater was needed to secure that the lobsters were calm and agile when released (van der Meeren, 1991b). Another experiment showed that lobsters released in cold water (5°C) were less aggressive towards each other, but not less agile and able to find shelter (van der Meeren, 1993). These results have been used to alter the release technique in the later large scale release project.

The first observations of the released lobsters were in 1989 by divers. The first recaptures came in 1990 (van der Meeren & Næss, 1991). The following years released lobsters were recaptured in an expanding area around the release site. Berried females has been recaptured in 1991. In 1993 lobsters with two cutting claws has been reported several kilometers from the release sites. Still no recaptures more than 500 m form the pilot scale release sites has been verified by the research team.

The temporary results from the large scale releases at Kvitsøy is given in table II. We expect the major impact of the first release to come in 1994. Still, the recaptures of the first release in 1990 has reached 2 % in 1993 (van der Meeren & Næss, 1993).

In the 1990 released lobsters, a majority (> 90%) bore two cutter claws, due to lack of substrate in the rearing facility. In the undersized lobsters, the morphology is more comperable to the wild stock, with a diminishing number of lobsters with two cutter claws (Tab. II). In lobsters released from 1991, 70-80% have developed a crusher claw.

Systematic fishing in the experimental release area has so far given two recaptures of undersized lobsters in 1993. Monitoring of both the large scale and experimental releases will be continued.

Discussion

The important results from the pilot scale release project, are 1) the knowledge about how transportation stress can be reduced prior to release, and 2) observations of the initial response showed by cultivated lobster juveniles to conditions they will meet after the release, such as low temperature, light, fish and conspcifics. This knowledge has been important in modifiing the traditional cheap and quick surface-release method ("sowing"), suited for large scale releases (van der Meeren & Uglem, 1993). Release time is now set to early spring, with calm weather conditions and 30 min of acclimatization to ambient sea water, in order to minimize loss to predators and inter-specific fighting.

The large scale releases has started to give information, but must be monitored for several years to come to give data enough to evaluate the success. So far we see that the local population is strongly influenced, since the released lobsters constitutes for near 40% of the undersized lobsters. A control monitoring is now initiated in nearby fisheries, to see if the population dynamics at Kvitsøy alters from areas with no releases.
At the moment we can not tell if the Kvitsøy lobster stock has been enhanced or dilluted by the released lobsters. Genetic analysis is done to see if the gene pool in the population is influenced by the released lobsters.

Both in the large scale and in the experimental releases we hope to gain new knowledge about lobster ecology and population dynamics, in addition to data on growth, survival and recapture success. Based on the lack of knowledge when the release projects were started, the release technique still suffer from lack of precision and security for the juveniles. Further research are needed to develop an optimal release technique which reduce long term mortality. Constructions of controlled experiments, testing hypotheses based on the progressive field work, will be needed. The large number of tagged lobsters of known age, released through five years in the same area, can in the coming years give invaluable information also about population dynamics and lobster ecology. Other problems to be solved is to choose the right lobster density in relation to bottom substrate and depth, to secure high survival rate also in the years following the release. Some information might come from the releases done from 1990 to 1994 in Norway.

The economic aspect of lobster releases in Norway can not be discussed this early in the research, but it is clear that the cost of producing lobster juveniles has so far been high. The recapture rate must therefore also be high to be economical viable.

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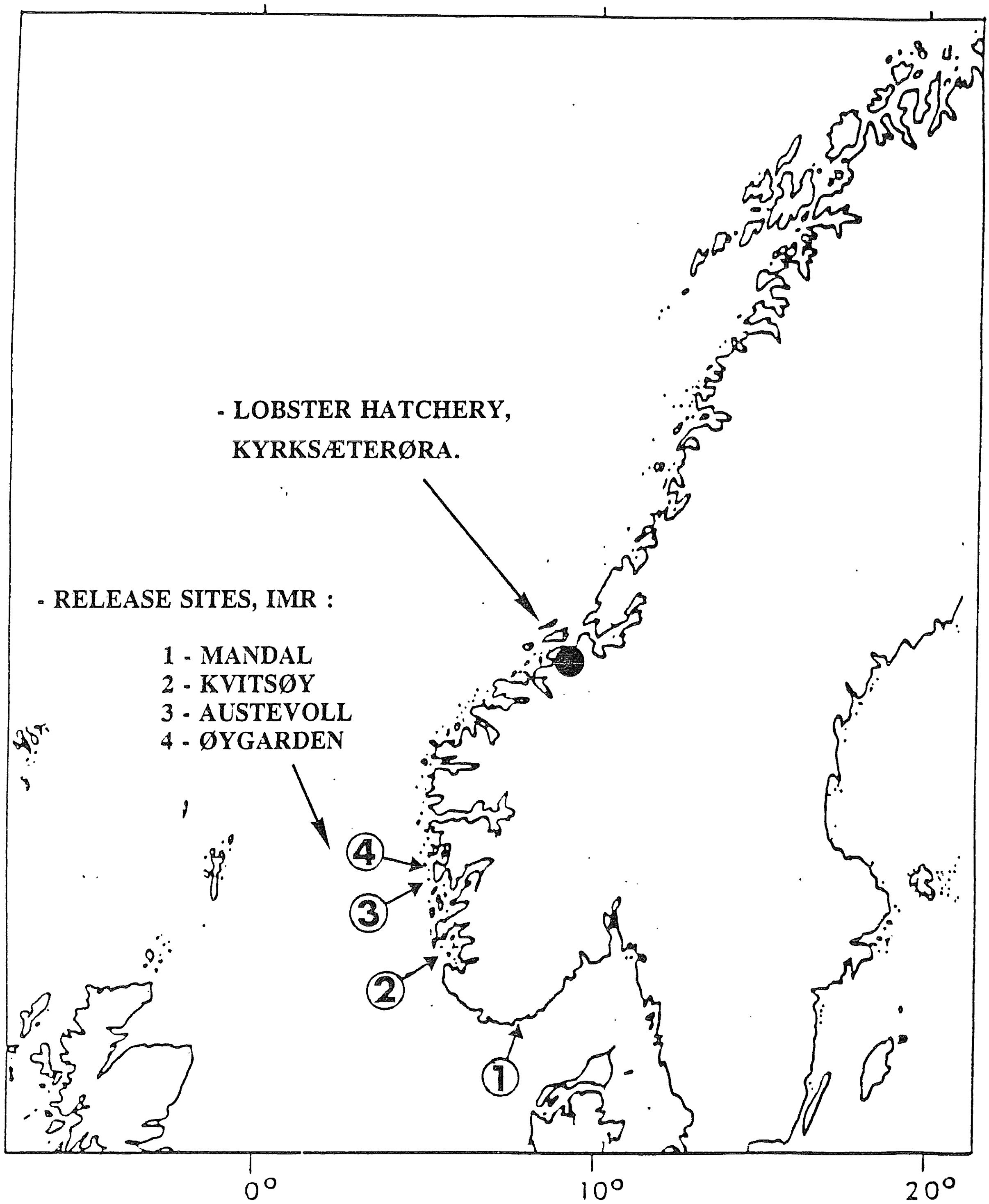

Figure 1.

Map over the release areas in Norway.

Table Ia.

Number of lobster juveniles in each release in the large scale releases at Kvitsøy. If nothing else is noted, the lobster juveniles are released less than one year old, in sheltered areas and onto varied bottom of sand and scree.

	> 1 year old	< 1 year old	Sand/ scree	Rocky bottom	Exposed	Total nos.
March 90	14 700	8 600				23 000
April 91		29 800				29 800
April 92		22 600				22 600
June 92		7 600				7 600
April 93	550	10 550	5 270	5 280		11 100
December 93		5 800				5 800
March 94		20 000			10 000	30 000
Total						129 900

Table Ib.

Releases by smaller lobster juvenile batches, testing the influence of release time of the year, different release densities, wave exposures, repeated releases in one area, bottom substrate and predation pressure immidiately after release. The total number of lobster juveniles released experimentally is given.

Season	Density	Exposure	Single- Repeated release	Substrate	Predation
March 91	+				
Dec. 91		+		+	
May 92			S		+
Dec. 92			R		+
Feb. 93			S	+	+
March 93			R		+

Total numbers 15 850

Table II.

Fraction of released lobsters, captured in the spring and autumn fishery at Kvitsøy. The difference between spring and autumn seems to be caused by the fishery exploiting mainly older lobsters in the spring and recruits in the autumn.

	Below Minimum legal size		Above Legal size
	Tagged	Double scissors	Tagged
Autumn 92	39,4	16,2	7
Spring 93	10,9	1,4	0,9
Autumn 93	38,8	9,5	12,6