# The Plaice Box: A summary of four evaluations

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## Background

### The Plaice Box

In 1987, the plaice (*Pleuronectes platessa*) stock in the North Sea was considered exploited beyond sustainable level. The fishing mortality was assumed over $F_{max}$ for this stock. Furthermore, pressure fisheries exerted on the plaice younger age classes was presumed to be too high to be sustainable. The North Sea Flatfish working group of the International Council for the Exploration of the Sea (ICES) was asked to provide advice to improve plaice exploitation patterns in the North Sea (ICES, 1987). In order to increase the long-term equilibrium yield of the North Sea plaice stock, management measures that could improve the exploitation patterns were investigated. Two potential measures were identified during this working group: (1) a reduction in gear mesh size, and (2) the implementation of a closed area. This working group's recommendations and the discussions with the fishing industry resulted in European Commission legislation in 1989 (EEC no 4193/88). This legislation defined a spatial closure of coastal areas of Denmark, Germany and the Netherlands to fisheries targeting plaice (Figure 1). This area, called the Plaice Box (PB), covered most of the undersized juvenile plaice distribution in the North Sea at the time (ICES, 1994).

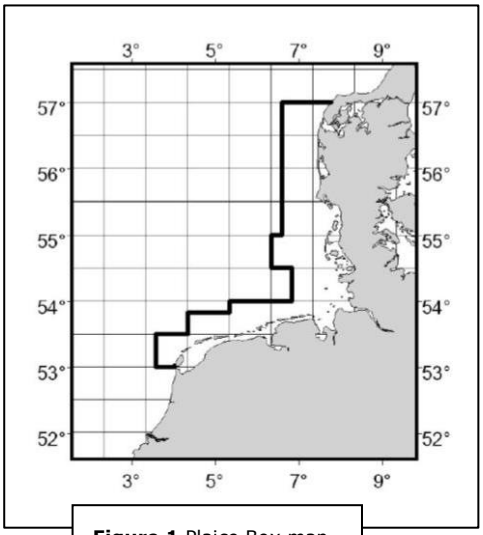


**Figure 1** Plaice Box map

### Biological objectives defined by the ICES

The PB management measures explored by the ICES Flatfish working group in 1987 were supposed to lead to two phenomena:

1) An increase in the Spawning Stock Biomass (SSB). This increase was estimated in comparison to the predicted SSB if the exploitation level in place in 1987 stayed the same ($SSB_s$). The estimation was done using a deterministic model. Based on the model projections, the SSB was supposed to increase with 25% compared to $SSB_s$, assuming a full closure of the area during the 2nd and the 3rd quarters of the year.
2) A decrease in the quantity of undersized plaice discarded in comparison with the discard rates occurring in 1987. This metric was not quantified in the model-based approach that led to the PB proposition.

### Management measures

Based on the North Sea Flatfish working group advice a protected area was created through European Council Regulation EEC No 4193/88. However, the PB did not fit completely the area advised by the ICES. From its beginning in 1989, the PB was closed to part of the fleet, forbidden to fishing vessels with engine power above 300 HP (221kW). From 1989 to 1993, the closure occurred during the 2nd and the 3rd quarter of the year only. In 1994, following the first evaluation, the PB closure was extended to the 4th quarter, to finally be closed all year around since 1995.

# Overview of evaluations

### Summary of evaluation findings

Since its implementation, the PB has been the subject of four evaluations in 1994, 1999, 2004 and 2010 (ICES, 1994, ICES, 1999, Grift et al., 2004, Beare et al., 2010). These were performed under the auspices of ICES and requested by the European Commission. The PB evaluations followed a cumulative pattern: data and analysis building up over time following further data acquisition and gaining ecological knowledge. The first evaluation tried to estimate the PB anticipated positive impacts on recruitment and discard rate. Based on this first evaluation, the second one explored the same parameters and the PB impact on plaice distribution. The third evaluation used the same metrics as the two first ones but also explored potential negative impacts of the PB and new environmental variable impacts. Finally, the fourth evaluation tried to explain if the negative trends in SSB observed in the PB were caused by the instalment of the PB or were due to other environmental causes.

All evaluations indicated a major difference between the original ICES working group advice (full closure) and the management measures implemented for the PB (closure for part of the fleet). All evaluations also highlighted the lack of clear objectives and experimental design at the PB implementation and how difficult it was to evaluate its performance. Data available and factors explored to estimate these performances progressively increased along the four evaluations (Table 1, Beare et al., 2013).

**Table 1.** Summary of all evaluation investigations and the 1987 pre-assessment from the North Sea Flat Fish working group, based on Beare et al., 2013. In italic processes that were recommended for further investigation were added.

| | ICES (1987) | ICES (1994) | ICES (1999) | Grift et al. (2004) | Beare et al. (2010) |
|---|---|---|---|---|---|
| **Ecological feedback processes** | | | | | |
| Growth | No | Yes | Yes | Yes | Yes |
| Mortality | No | No | No | No | Yes |
| Distribution | No | No | Yes | Yes | Yes |
| *Density-dependence* | No | No | No | No | Yes |
| **Ecosystem changes** | | | | | |
| Recruitment | No | No | No | Yes | Yes |
| Eutrophication | No | No | No | Yes | Yes |
| Trawling impacts benthic productivity | No | No | No | Yes | Yes |
| *Trawling impact flatfish diet* | No | No | No | No | No |
| Climate change | No | No | No | Yes | Yes |
| *Predation (seals and cormorants)* | No | No | No | No | No |
| **Fleet dynamics** | | | | | |
| Redistribution of fishing effort after PB | Yes | Yes | Yes | Yes | Yes |
| Developments in fleet capacity | No | No | No | Yes | Yes |
| Competition among fleets | No | No | No | No | Yes |

Stakeholders' perceptions presented in the fourth evaluation emphasized the PB as a management failure. In addition, the plaice SSB reduction in the area is often attributed to the PB implementation

itself. However, the last PB evaluation explored this possibility, and no evidence supports a negative impact of the PB at this time. Furthermore, model-based approaches consistently indicated positive impacts of the PB on the SSB.

## First evaluation 1994

*Scope*

The first PB evaluation (ICES, 1994) explored the changes in fishing effort in the area, as well as the PB effects on plaice stocks through recruitment and discard rates. The first evaluation also offered the opportunity to re-run the deterministic model used before the implementation of the PB.

The model-based approach was conducted through a deterministic estimation of plaice biomass under different equilibrium effort levels. It was based on the same model as the one from the North Sea Flatfish working group from 1987. Fishing effort was estimated quarterly at ICES rectangle level. This approach meant that different scenarios for the implementation of PB management measures could be evaluated. Scenarios explored management measures that implied closure occurring during all quarters of the year or a subset of quarters, as well as management measures that implied full closure of the area to the entire fleet or partial closure. The evaluation also explored the hypothesis of a negative feedback on plaice growth rate. This negative feedback would have been caused by density dependent mechanisms due to the PB implementation. If plaice density had increased due to the PB, it may have caused intra-specific competition between individuals for resources such as food. Consequently, this would reduce the plaice growth rates. This hypothesis was explored as a decrease in plaice growth rate in the area had been observed since 1980. The model was modified to include potential growth rate decreases.

*Findings*

In comparison to the model developed prior to the PB implementation, the new model based on partial closure of the PB reduced the estimated SSB gain from a 25% increase to an 8% increase.

From this first evaluation no clear improvements of the SSB and discards rates could be attributed to the PB. However, the management measures implemented in European policy differed from the ones used in the first model-based approach to estimate potential performances of the establishment of a PB (ICES, 1987). This gap between ICES recommendations and actual management measures agreed at policy level might have explained at least part of the differences between benefits predicted and the PB real protection outputs: "The effect of continued fishing by exemption fleets has been to reduce the predicted gain of a closure the 2$^{nd}$ and 3rd quarter to 8% compared with 25% estimated previously" (ICES, 1994).

*Recommendations*

The first evaluation did not present recommendations. However, the results of the model approach conducted in this evaluation led to a change in management measures from a two-quarter closure to a full-year closure of the area.

## Second evaluation 1999

*Scope*

The PB second evaluation (ICES, 1999) focused on suitable performance metric definitions. The previous evaluation only used recruitment as a performance metric. This did not seem to be appropriate. Plaice recruitment in the area appeared to be highly dependent on environmental conditions. This made it hard, without a proper experimental design, to differentiate changes due to the establishment of the protected area from broader spatial and temporal changes in both the plaice stock and the environment.

The main aim of the PB was to lead to a reduction in the discard rate of undersized plaice, which was assumed to lead to an increase in commercially exploitable plaice. Therefore, ICES identified the trend in cumulative discard mortality until cohort reached minimal landing size as a suitable performance metric. However, data needed to quantify this cumulative discard mortality metric were not consistent before

and after the PB implementation. Furthermore, the lack of a control area complicated the differentiation between temporal changes and PB effects.

The trend in cumulative discard mortality (i.e. summing discard mortality at-age for a cohort until it reaches minimum landing size) was explored using several factors: the fishing effort trend, the discard rates, and the pre-recruit mortality. Furthermore, some additional processes were explored to understand this trend in cumulative discards: environmental conditions (abiotic and biotic factors), distribution, growth and plaice and sole feeding habits.

*Findings*

The evaluation concluded that cumulative discard mortality until cohorts reached the minimal landing size did not change significantly from 1989 to 1999. Moreover, a decrease in undersized plaice numbers within the PB was observed between the first two evaluations of the PB (1995-1999).

This change in undersized plaice numbers might be explained by a modification in spatial distribution. During the period 1995-1999, juvenile plaice moved from coastal (protected) water to the border of the PB. In the last years before the second PB evaluation (in 1999), the largest number of undersized plaice occurred at the border of the PB. Considering the new plaice distribution as well as the unchanged high values in discard rates, the PB was most likely to offer a reduced protection compared to the one estimated at its implementation and during the first evaluation.

*Recommendations*

The second evaluation highlighted, without details, the need for an appropriate experimental design to assess changes induced by natural causes from changes induced by the closed area.

### Third evaluation 2004

*Scope*

This evaluation was designed to use all available parameter trends together (landings, efforts, discards rates, growth rates, spatial distribution of juveniles and environmental parameters) to determine the PB's effectiveness. Regarding the PB effectiveness evaluation, a change in access rights to the PB might have been explored. The European Commission considered modifying access to the area if clear positive or negative impacts from the PB had been identified.

To investigate the trends from all these parameters the same data as in previous PB evaluations were analysed. In addition, the biotic and abiotic trends of environmental variables such as benthos productivity, eutrophication or water warming were quantified for the first time.

*Findings*

The main conclusions were that despite a decrease in fishing effort (69% from 1989 to 1994 and a further decrease of 23% from 1995 to 2003), the plaice total recruitment, the SSB and yield decreased since 1989.The discards rates increased inside and outside the PB (from 77% to 87% inside the PB and from 31% to 77% outside the PB, 1976-2003 period). However, the difference in discard rates between the inside and outside of the PB decreased (46% of difference in 1976 and 10% in 2003). The hypothesis of a change in young plaice distribution presented in the previous evaluation was confirmed: in 1987 the PB 'housed' more than 90% of the undersized plaice, compared to less than 70% in 2003. The observed decrease in growth rate in the 1980s stopped and growth rates stabilized around 2003. However, inter-annual variation in growth rates increased from 1994 to 2003. Environmental variables also changed during the same period. Sea water temperature increased in average by 0.5-1°C from 2000-2003 with high values, especially in winter. Nitrogen and phosphorus concentrations declined from 1980 to 1990 and primary production [phytoplankton at the base of the food chain] increased from 1970-1980 and declined progressively from 1990-2003.

This third PB evaluation (Grift et al., 2004) fostered the idea of a change in plaice distribution that had limited the protection the PB was supposed to give to juveniles. Furthermore, this evaluation presented potential causes of distribution shifts such as global warming and nutrient decline and tried to quantify these environmental variables in the PB area. Negative trends were observed for the entire North Sea plaice stock from 1989 to 2004. Considering this negative trend, the PB may have had a positive impact on local recruitment, but its benefits had progressively decreased due to distribution shifts from coastal to more offshore areas. The evaluation also considered how a reduction in trawling intensity in the PB may have contributed to a decrease in the density of prey available to plaice. This hypothesis was brought forward by the fishing industry. However, no data or scientific literature supported this hypothesis at this time. Furthermore, local trends fitted overall plaice stock trends in the North Sea, where no change in fishing intensity occurred during the same period.

*Recommendations*

The third evaluation detailed the steps needed when implementing a closed area. However, part of them were not applicable to the PB anymore since they needed to be defined before the implementation of the management measure. The steps were identified as follows; define specific aims and objectives related to the closure; define relevant and measurable criteria to quantify the performances of the management measures against the objectives; design a research program to collect the data necessary to monitor the effect over a predetermined time scale. This research program needs to be designed in a way which allows the separation of closure effect from autonomous developments making use of control areas.

## Fourth evaluation 2010

*Scope*

The fourth PB evaluation (Beare et al., 2010) highlighted the decline in North Sea plaice stock biomass. It questioned its reasons and the role the PB might have played in the North Sea plaice stock biomass decrease. It explored the PB impacts using a broader ecosystem-based approach compared to the previous evaluations through plaice stock, community, and environmental changes. Furthermore, it assessed the socio-economic impact. The PB acceptance was also an important focus, through an investigation of the PB stakeholders' perceptions. The usual variables were analysed: fishing effort and discards trends, change in plaice dynamic and distribution and environmental variables. However, new factors were explored to understand plaice interactions within the ecosystem through fish and benthic community variations. Two new quantitative models were developed considering the new hypothesis on the processes occurring in the PB, to predict long term PB effects. The first model investigated the effect of density dependence on the PB performances based on a fully size structured population model. The second model, based on the original PB model, explored through a spatially explicit formulation the effect of a change in PB spatial limits. Finally, the socio-economic impacts of a change in management measures on the different fleets occurring in the area were analysed.

*Findings*

Both model-approaches indicated that the PB most probably had a positive impact on the SSB. The SSB reduction observed was unlikely to be caused by the management measures itself and most likely due to a reduction in area productivity. The decrease in beam trawl fishing effort from 1990 to 2008 was estimated to be 86% of the pre-PB level. However, the PB stayed an important fishing area for smaller vessels, especially the shrimp fishery and the mixed flatfish fishery which earn more than 70% of their revenue within the PB. The changes observed in plaice distribution remained similar to those observed in previous evaluations. Furthermore, plaice growth rate decreased with higher population density. However, the benefit due to a gain in density caused by a reduced discard mortality was supposed to be higher than the loss due to this decrease in growth rate.

Two changes in management measures were explored using a model approach. (1) A re-opening of the PB area to the entire fleet. Re-opening the PB was expected to lead to a slight increase in plaice discard numbers (<5%). (2) An extension of the PB area. Extending the PB to encompass a higher proportion of

juvenile plaice would only result in a moderate reduction of plaice discards (<10%). However, changing the design of the PB would have made evaluating before-after impacts very difficult. Indeed, because of the variability in natural recruitment benefits could not be measured accurately without a control area. Any change in PB management, especially a full re-opening, would have led to a reduced monetary yield by small fisheries. Indeed, the PB management benefited to small fisheries, mainly the shrimp fishery, while it had negative economic impacts on bigger trawl fisheries for flatfish.

The change in plaice distribution may be attributed to environmental changes, and in particular increases in water temperatures: similar changes in distribution patterns were observed outside the PB. Abundance of demersal species in the PB decreased. This decline in abundance was mainly due to a decline in the major species, such as plaice. Beam-trawling may have resulted in changes in the composition of benthic community plaice were feeding on. Those changes might have been favourable or detrimental to plaice. The lack of experimental design of the PB makes it impossible to draw conclusions. The presence of such shifts in benthic communities has been observed in comparable areas presenting variable fishing intensities. It may indicate that these changes in communities within the PB have been caused by environmental variables changes such as water eutrophication.

To better understand the effectiveness of the PB, performances of other fisheries dedicated Marine Protected Areas (MPAs) were reviewed. The evidence of demersal fisheries MPAs' ability to rebuild stocks and benefit fisheries is not strong within North Europe fisheries. However, some positive MPA examples from the USA show strong rebuilding and spill-over effects. All MPA examples considered in this review illustrated the need for (1) clear MPA objectives and (2) knowledge of the ecosystem processes occurring within the area of the MPA.

Fishers and Environmental non-governmental organizations (ENGO) considered PB as a management failure. ENGO stakeholders attributed part of this failure to changes in environmental conditions, while fishers mainly attributed the decrease in plaice SSB in the PB to fishing effort reduction (food availability reduction).

*Recommendations*

The fourth evaluation suggested an experimental design that would allow to determine positive or negative effects of the PB. A scientific question was defined: "Is the decrease in yield and spawning stock biomass of plaice caused by the establishment of the plaice box or caused by natural processes, or a combination of the two?"

Eight processes that might have been involved in the yield and spawning stock biomass decreased were identified. These processes were split between natural and fisheries induced processes, the second being the easiest to test. The natural processes identified were (1) settlement of plaice larvae in the box (2) predation (e.g., Seals, cormorants) (3) benthic productivity (eutrophication) (4) abiotic factors (temperature, oxygen). The fisheries induced processes identified were (1) fishing mortality (landings and discard) (2) thinning of the population leading to density-dependent growth (3) trawling impact on benthos may affect growth rate (4) changes trawling disturbance may influence the spatial distribution of plaice (Beare et al., 2010).

To understand these processes, five fisheries specific questions would have to be explored, and field and laboratory experiments developed to test them.

1) What is the effect of trawling intensity on benthic productivity and the food availability of plaice? This question was suggested to be tested through a field experiment, with 2 to 3 sites closed to all fisheries for 5 years and then trawled following an experimental set up to sample benthos and plaice (isotope/stomach content).
2) What is the effect of trawling intensity on the spatial distribution of pre-recruit plaice? This second question might be tested through a field experiment with modification of the PB borders, to compare the plaice distribution while overpassing the depth/disturbance current relation.

3) What is the effect of water temperature on the spatial distribution and growth rate of pre-recruit plaice? A laboratory experiment testing water temperature effect on plaice juvenile, statistical analysis of survey data including water temperature and field experiments through tagging might answer this third question.
4) What is the effect of the density of plaice and other food competitors on the growth rate of pre-recruit plaice? Statistical analysis of 1- and 2-year-old plaice in relation to plaice and other competitor distribution would give insights on this question.
5) What is the effect of the current PB on the survival and subsequent recruitment of pre-recruit plaice? All other questions element of answer might be used trough a model-based approach to answer this final question.

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