

**Evaluation of the effects of a closed area in the North Sea ('Plaice Box') on
the stock development of plaice (*Pleuronectes platessa*)**

M.A. Pastoors, A.D. Rijnsdorp and F.A. Van Beek

Abstract

The plaice box, a partially closed area in the North Sea, was established in 1989 to reduce discarding of undersized plaice (*Pleuronectes platessa*) in the main nursery areas and thereby enhance the recruitment to the fishery. Despite the plaice box, yield and spawning stock biomass have decreased. This paper evaluates the effect of the plaice box by analysing the relevant factors and processes (natural and anthropogenic) operating in the plaice box that affect the level of recruitment. It is concluded that the overall beam trawl effort in the box decreased to around 6% of the level before the establishment of the box reducing the discard mortality rate in the box. However, other processes such as a reduced growth rate and possibly a higher rate of natural mortality have counter affected the reduced discard rate. The changes in growth and mortality coincide with changes in the North Sea ecosystem that occurred in the early 1990s. The changes may also be due to the changes in level of beam trawl effort which may have led to a reduction in the food supply for plaice. However, as no direct evidence is available, the latter hypothesis needs further study.

1 Introduction

In 1989, a protected area in the south-eastern North Sea was established to reduce the discarding of undersized plaice (Council Regulation EEC No. 4193/88). In the 'plaice box' (beam-) trawlers larger than 300 hp were expelled during the second and third quarter of the year. In 1994, the regulation was extended to the fourth quarter. Since 1995 the 'plaice box' is closed during the whole year (Figure 1).

Contrary to the expectation, however, the landings and SSB of plaice have decreased substantially since the establishment of the 'plaice box' in 1989. At present, SSB is at an all time low value well below the minimum biologically acceptable level which was set at 300,000 t giving concern about the future recruitment. A feature of the recent stock assessments has been the discrepancies between the predicted recruitment from pre-recruit surveys and the ultimate recruitment observed in the virtual population analysis (ICES 1995, 1996, 1997a, 1998).

The basis for the 'plaice box' was laid during an ad hoc meeting of the ICES North Sea Flatfish Working Group which used a static model to estimate the changes in Yield and SSB per recruit under various fishing patterns (ICES, 1987). Using quarterly data on the distribution of fishing effort, the distribution of age groups and the distribution of the proportion undersized plaice per ICES rectangle, the group calculated the expected gain in recruitment to the fishery for various scenarios. The group made the following assumptions:

1) the spatial distribution of the fish was fixed and was not affected by fishing patterns or by changes in growth rate; 2) growth rate was constant and was independent of density; 3) all fishing effort was expelled from the box. The calculations showed that a closure of the box during the second and third quarter would increase recruitment to the fisheries by about 25%. Additional closure during the first and fourth quarter would further enhance the recruitment by 7% and 2%, respectively (ICES, 1987).

Under the regulation imposed in 1989, the effect of the 'plaice box' is likely to be less than the 25% predicted originally. The introduced box differed slightly from the box analysed by the Working Group in 1987 (Figure 1). Furthermore, fishing in the box was continued with small vessels (≤ 300 hp), and larger vessels fished heavily in the box after it opened again in the 4th quarter. In addition, the exemption fleet of vessels smaller than 300hp increased in capacity.

In 1994, the *ICES Study Group on the North Sea Plaice Box* re-assessed the 'plaice box' using the same methodology, but using additional data on fishing effort (ICES, 1994). The original expectations of the 'plaice box' during the second and third quarter were lowered from 25% to 9%, but it was shown that an extension to the fourth quarter would improve the yield and SSB to 19%. If all fishing was expelled from the box during the whole year, the overall gain was close to the original estimate (24-27%).

It is important to note that the plaice box will have an impact on the *relative* level of recruitment by reducing the discard mortality rate. The *absolute* level of recruitment will be affected by at least four processes: 1) larval influx in the box, 2) discard mortality rate, 3) natural mortality rate, 4) time period during which the undersized fish are exposed to discard mortality (Figure 2). The number of larvae that settle in the coastal nursery grounds is affected by highly variable environmental factors and is not directly related to fishing. During the juvenile phases, plaice in the box is subject to natural mortality (birds, fish, seals, diseases) and to discard mortality. Growth rate will influence the duration of the juvenile phase. When growth rate is high, a large proportion of the larvae will survive because of the reduced time period during which undersized plaice are exposed to mortality factors (every other factor being similar).

In this paper we will review the relevant processes that affect the survival of pre-recruit plaice in their nursery areas along the continental coasts. First, we will analyse changes in beam trawl effort. Second, the changes in growth rate, mortality and recruitment will be analysed. Finally, we will apply the dynamic simulation model of Rijnsdorp & Pastoors (1995) to explore the interrelationships between growth rate and discard mortality under different plaice box scenario's.

2 Material and methods

2.1 Recruitment estimates

Recruitment estimates were available from the North Sea plaice VPA (ICES 1998) and from pre-recruit surveys conducted in the main nursery areas of the south-eastern North Sea. The VPA recruitment estimates are updated using the 1996 data for the international plaice landings and corresponding age structure (ICES, 1998).

The discrepancies between recruitment survey indices and VPA estimates of year class strength are estimated by a linear regression of the $\ln(\text{survey abundance})$ and the $\ln(\text{VPA estimate})$. Discrepancies (residuals) are expressed as the $\ln(\text{observed}) - \ln(\text{predicted})$ value,

where 'observed' is the VPA estimate and *predicted* is the estimate based on the linear regression.

The total mortality Z for cohorts during the first years of life is estimated from the ratio of the *ln survey catch rate* between successive years:

$$Z_{a,y} = \ln \left(\frac{N_{a,y}}{N_{a+1,y+1}} \right)$$

2.2 Growth rates

Growth rate of juvenile plaice is studied by estimating the mean length of juvenile plaice using pre-recruit survey data (DFS, SNS) collected since 1970 in September-October. The 0-group size is estimated from the DFS survey which samples the shallow coastal waters from the Belgian coast to Esbjerg. The size of the 1-, 2- and 3-group is estimated from the SNS survey data which covers slightly deeper waters in the same area.

A second independent data set consists of otolith back-calculations of female plaice collected between 1948 and 1995 in market sampling programs (Rijnsdorp & van Leeuwen, 1996). This data set is used to estimate the mean size at age 1 to 4 for the year classes born since 1970.

The Von Bertalanffy growth parameter K was calculated using the following equation:

$$K = -\ln \{ (L_{a+1} - L_{inf}) / (L_a - L_{inf}) \}$$

in which a is the age, L_a is the length at age a , and L_{inf} is the presumed length at infinite age. In order to give comparable results with those obtained from the simulation model, L_{inf} was fixed at $L_{inf} = 47.3$.

2.3 Fleet composition and fishing effort

Data on international and Dutch effort is available from several sources:

- 1974-1977 international effort distribution (ICES, 1987)
- 1989-1991 international effort distribution (ICES, 1994)
- 1990-1997 Dutch effort data by trip (Van Beek et al, 1998)
- 1994-1997 Dutch micro-scale distribution data (Rijnsdorp et al, 1998)

In this paper we used data from the mid 1970s and from the Dutch effort database.

International effort data from the period before the implementation of the plaice box is available from the ad-hoc ICES Flatfish Working Group, which met in 1987 (ICES, 1987). In this Working Group data from the mid 1970s were assembled and expressed in a single unit. The average distribution of effort by rectangle was calculated by taking the simple arithmetic mean by quarter and by rectangle over the years 1974 to 1977.

Fishing effort for the Dutch beamtrawl fleet is available from logbook data since 1989. However, because the first year of logbook registration is considered unreliable, the data-series is used from 1990 - 1997 (Van Beek *et al*, 1998). The data-set contains catch, effort and vessel data per ICES rectangle and per trip. Trips were selected for analysis when they fulfilled the following criteria: 1) beamtrawl gear used, 2) engine power larger than 225 HP, 3) landings of plaice and sole reported, 4) ICES rectangle reported. Effort was calculated as days-at-sea and horse-power days-at-sea. In trips where more than one ICES rectangle was visited, effort was split according to the estimated value of the plaice and sole landings in

each rectangle whereby it was assumed that the market value of sole is roughly 5 times the value of plaice.

Level and distribution of effort of the Dutch beamtrawl fleet just prior to the establishment of the plaice box (late 1980s) was calculated under the assumption that the overall level of effort was constant (hence total effort in 198x is equal to total effort in 1990), but that the distribution of effort had changed.

Trends in effort distribution were analysed by subdividing the North Sea in three areas: plaice box - border (just outside the plaice box) - other (Figure 3). Logbook data is available for ICES rectangles only. Since the plaice box does not cover whole ICES rectangles assumptions had to be made to subdivide effort in so-called 'mixed rectangles' of which only a part was in the plaice box. We assumed that all effort and landings by large beam trawlers in periods when the box was closed was effectively exerted just next to the box (the border area). If the box was not closed (e.g. the 4th quarter in the years 1989-1993) we assumed that the effort in the mixed rectangles was effectively exerted in the box.

2.4 Simulation model

The model of Rijnsdorp and Pastoors (1995, see also Pastoors et al, 1997a,b) simulates the basic biological processes of growth, recruitment, migration and mortality employing a resolution of ICES rectangles (one degree latitude and 0.5 degrees longitude, approximately 30x30 miles) and a variable time step of 1 week or less. The simulated population consists of six size classes:

- (1) pre-recruits (5-14cm);
- (2) discards (15-26cm); and
- (3-6) four commercial market categories (27-33cm, 34-37cm, 38-40cm and ≥ 41 cm).

The monthly migration vectors (direction and speed) were estimated from tagging experiments. Migration rate increased with the size of the fish. Fishing is simulated by calculating the number of fish caught in each spatial unit in each time step, given the number of fish present and the level of fishing effort.

The model structure and parameter setting presented by Rijnsdorp & Pastoors (1995) was slightly modified (Table 1). Migration rates of the two smallest size classes were reduced to 0% and 50% of the original values, in order to calibrate the model to the observed values of the percentage of discards in the offshore rectangles (see Fig.10 in Rijnsdorp and Pastoors, 1995). Catchability on recruited size-classes (q2-q6) and growth parameters (K) were calibrated by maximizing the goodness of fit between simulated and observed mean length at age, and between the simulated exploitation pattern and the VPA-estimated pattern. Because recruitment to the fishery does not start at 15 cm but at 18 cm (van Beek, 1991), the catchability (q2) of the discard size class was reduced to 75% of the q3-q6. These modifications in input parameters reduced the percentage of discards from 55% in the original run (Rijnsdorp and Pastoors, 1995) to 46%, which compares to an estimated percentage in the 1980s of 50% (van Beek, 1990). As such, the model results may be conservative with regard to the effect of a closed area and the corresponding reduction in the level of discarding.

The plaice box scenario's explored were similar to those explored in the 1994 meeting of the ICES Study Group on the Plaice Box (ICES, 1994). A summary of the scenarios is given in Table 2. The scenario's include a scenario reflecting the situation in the 1970s and 1980s without a plaice box (scenario A), one with the regulation imposed between 1989-1993

with a plaice box during the second and third quarter (scenario B), one with the plaice box closed during the second, third and fourth quarter (scenario C), one with the plaice box closed during the whole year (scenario D) and finally one with a plaice box in which no fishing is allowed (scenario E). The effort distributions for these scenarios as well as the initial distribution of recruits (5-15cm size class) over the nursery areas was similar to that used in the Working Group (ICES, 1987, 1994).

3 Results

3.1 Fleet composition and fishing effort

North Sea plaice is taken in a mixed fishery for plaice and sole in the North Sea. The main fleets active in this fishery are the Dutch beam trawl fleet (taking 44% of plaice landings in 1996), the English beamtrawl fleet (17%) and the Danish fleets (15%). In recent years a number of Dutch vessels have been re-flagged to England, Scotland, Germany and Denmark. The analysis presented here is built on data for the Netherlands only.

Figure 8 shows the mid 1970s spatial distribution of fishing effort per quarter for the Dutch beamtrawl fleet. In the second and third quarter of the year there was heavy fishing activity in what would later become the plaice box area.

If we assume that the overall level of fishing effort for the Dutch fleet was more or less constant in the years around the establishment of the plaice box, we can calculate the distribution of effort just prior to the box by taking the relative distribution from the mid 1970s together with the overall level of the late 1980s. Before 1989, the Dutch beamtrawl effort in the plaice box was highest in the 2nd and 3rd quarter. After establishment of the beam trawl effort in the 2nd and 3rd quarter was greatly reduced, but after reopening the box on October 1st, the fleet of vessels larger than 300 hp moved into the box to exploit the rich fishing grounds (Figure 9).

A study of the micro-scale distribution of Dutch beam trawl vessels, using an automated position recording system, revealed that the fleet of large vessels, heavily exploits the borders of the plaice box (Rijnsdorp et al, 1998). It was further shown that the plaice box has been effective as a technical measure in closing the area to fishing by large beam trawlers.

One of the fundamental aims of establishing the plaice box, was to diminish the total level of trawling in the box area and thereby reduce the discard level of undersized plaice. Figure 10 shows the reconstructed effort level (in horsepower days) for the Dutch fleet fishing in the plaice box. The 1980s level was estimated from the mid 1970s effort distribution (inside box-outside box) at the same overall level of fishing effort as in 1990. Fishing effort in the first four years of the box diminished to around 40% of the pre-box level. In recent years, fishing effort in the box is only at around 6% of the pre-box levels.

Fishing effort (days at sea) for the overall Dutch eurocutter fleet (225-300 hp) has remained relatively stable in the period 1990-1997. For the large cutters an effort increase is observed in the years 1994 and 1995, followed by a sharp decrease in 1996 and 1997 possibly due to quota restrictions (Figure 11). A striking feature is that the overall effort of the eurocutter fleet has been rather constant, but the distribution of the fleet has certainly not been constant. Figure 12 shows how the proportion of effort for this fleet segment increased in

the period 1990-1993 and decreased since then. It can be concluded that although the box was closed for the larger vessels in recent years, the small vessels have not been able to profit.

Although no comprehensive set of effort data is available for all the relevant fleets, it is clear from the available evidence that the effort in the plaice box was reduced since 1989 and in particular since 1994.

3.2 Survival of pre-recruits

The survey indices of the abundance of pre-recruits in autumn allow the estimation of the overall mortality Z for each age group between age-0 and age-3. Because the various surveys target at different age-groups, the mortality between 0- and 1-group can be estimated from the change in DFS and SNS index. The mortality of the 1- to 2-group and the 2- to 3-group can be estimated from the SNS and BTS indices, and that of the 3- to 4-group from the BTS-survey only.

Although the mortality estimates are rather variable, they indicate an upward trend in time, both for the 0/1 and the 1/2 mortality (Figure 4). These trends indicate a rise in juvenile mortality after the closure of the plaice box. The higher mortality is unlikely to be related to the level of fishing mortality in the coastal waters. Two possible factors are: 1) changes in the temperature profile of the North Sea due to exceptionally warm conditions around the beginning of the 1990s. 2) an increased predation on juvenile plaice (e.g. increasing number of cormorants in North-Western Europe, which have extended their feeding areas to the Wadden Sea and the shallow coastal waters, van Eerden and Gregersen, 1995).

3.3 Growth rate

The decrease in growth rate of juvenile plaice in the late 1980s is clearly reflected in the mean length at age in the pre-recruit surveys as well as in the back-calculated length (Figure 5 and Figure 6). Expressed as the Von Bertalanffy growth coefficient K , a similar pattern emerges with low growth for the year classes born between 1985 and 1989 (Figure 7). Growth of the year classes born in 1990 and later appears to have recovered to the level of the early 1970s. The drop in growth rate in the late 1980s coincided with an increase in the abundance of juvenile plaice as reflected in the biomass of 2- and 3-group plaice.

3.4 Simulations

While the percentage discards declined, recruitment to the fisheries increased with increasing growth rate (Figure 13). The yield and SSB per recruit showed a similar increase.

The simulations show that the closure of the 'plaice box', under the assumptions of the simulation model, reduces the percentage of discards in the catch and enhances the landings and SSB per recruit (Figure 14). Closure of the box during the second and third quarter (scenario B), reflecting the regulation between 1989 and 1993, gave a slight increase of about 6% (landings) and 9% (SSB) (Table 3). Extending the 'plaice box' to the whole year, reflecting the situation since 1994, further enhanced the landings and SSB by 15% and 31%, respectively. The improvement is mainly due to the reduction in discarding during the fourth quarter (compare scenario B and C), because the fisheries mainly operate on the offshore fishing grounds outside the 'plaice box'. Extending the box by excluding all vessels during the whole year (scenario E) increased the landings per recruit by 35% from 0.204 to 0.275 and the SSB per recruit by 64% from 0.314 to 0.544 (Table 3). Comparing the gain in

landings and SSB with that in the percentage recruitment reveals that the increase is mainly due to an increase in the survival of pre-recruits which results in an increase in the recruitment to the fisheries (%recruitment). The %recruitment was calculated by cohort analysis of the numbers at age landed by the fisheries.

The effect of the 'plaice box' is influenced by the growth rate. Changes in growth rate of about 20% may substantially affect the landings and SSB per recruit (Figure 15). The positive effect of the 'plaice box' will decrease if combined with a decrease in K. On the other hand an increase in growth rate will further enhance the effect of the 'plaice box'.

4 Discussion

The recruitment to the fishery, as estimated by VPA of the commercial landings, is affected by both the natural processes determining the level and variability in the numbers of 0-group plaice settling in the nursery areas, and by the survival of pre-recruits until the time when they reach the marketable size. The number of 0-group plaice settling in the nursery areas is mainly determined by the variability in environmental conditions during the egg- and larval phase (van der Veer et al., 1992). This interpretation is supported by the general significant positive correlations between the 0-group abundance in autumn and the VPA estimate of year class strength.

With regard to the other side of the recruitment problem (the stock-recruitment relationship) it is expected that at low levels of SSB, the average number of settlers will be reduced. However, the exploitation history of plaice does not indicate at what levels of SSB this may occur (ICES, 1996).

Our analysis focuses on the mortality of pre-recruits which is affected by discard mortality and natural mortality. The ultimate survival of pre-recruits will be a function of the cumulative natural and discard mortality rate.

4.1 Instantaneous mortality rates

The reduction in beam trawl effort in the plaice box implies that the discard mortality rate in the box area must have decreased. This inference is supported by the increase in the relative abundance of larger size classes of exploited species as observed in the beam trawl survey catches in August - September (Piet & Rijnsdorp, 1998). A reduced discard mortality rate, however, is not reflected in the survival indices estimated from pre-recruit survey indices, which suggested a lower survival of the 1990 - 1994 cohorts (Figure 4). This apparent discrepancy may be to the fact that the reduction in beam trawl effort was restricted to the second and third quarter. The heavy beam trawling in the plaice box during the fourth quarter in the period until 1994 will have generated a substantial discard mortality which will have affected the year classes 1987-1991.

The apparent decrease in survival of cohorts born since 1990 remains puzzling. The lower survival is unlikely due to the level of fishing effort in the coastal waters. Logbook information of the Dutch eurocutters, which are allowed to fish within the 12 miles zone and in the plaice box, show that effort has increased slightly between 1990 and 1995. However, the fishing effort in the plaice box has been at a constant level between 1990 and 1993 (Figure 9 and Figure 10). No data are available on the trends in effort of the German fleet, although the effort of the Dutch eurocutters under foreign flag made about 1700 days

at sea in the plaice box in 1995. A possible explanation of the lower survival of these cohorts is the increased abundance of cormorants which have extended their feeding areas to the Wadden Sea and shallow coastal waters (van Eerden and Gregersen, 1995). Leopold et al. (1998, in press) have shown that these piscivorous birds showed a preference for flatfish and in particular plaice.

The reduced survival may also be related to changes in the North Sea ecosystem that occurred in the early 1990s and that may confound the effect of the plaice box. Corten and van der Kamp (1996) showed that in the early 1990s an increase in the abundance of southern fish species occurred in the southern North Sea. This change was related to relatively mild winters and an increase in southerly winds which resulted in an increased transport of Atlantic water through the Strait of Dover. An analysis of the demersal fish assemblage in the south-eastern North Sea showed significant changes in the species composition and abundance (Piet and Rijnsdorp, 1998). The changes occurred in the plaice box as well as in two reference areas. These results indicate that a change may have occurred in the North Sea ecosystem around the time of the establishment of the plaice box.

4.2 Cumulative mortality rate

A decrease in growth rate will extend the pre-recruit period and hence increase the cumulative mortality. The observed decrease in pre-recruit growth in the late 1980s and early 1990s corresponded to a reduction from $K=0.30$ to $K=0.25$. The simulation model showed that this decrease in growth rate confounded the effect of the plaice box (Figure 15). The decrease in the growth results in a change in the yield of -14% (scenario A: no box) as compared to the situation of high growth rate and no plaice box. Concurrent with the decrease in growth, the plaice box was established in the second and third quarter which improved the yield to -9% (scenario B) which is still below the yield at a high growth rate without a plaice box. Extension of the plaice box regulation to the whole year (scenario D) would lead to a change in yield of -1% and a change in SSB of +15% if growth rate continues to be low.

The analysis of the growth rate of different size classes of plaice showed statistically significant contributions of density-dependent (population abundance) and density-independent factors (eutrophication, beam trawl effort) (Rijnsdorp and van Leeuwen, 1996). The decrease in growth rate in the late 1980s, thus, can be (partly) ascribed to the increase in the number of pre-recruits following the recruitment of the strong 1985 year class. The higher growth rate in the 1990s supports this interpretation as the number of pre-recruits in the nursery areas was substantially lower. It remains to be seen whether the pre-recruit growth rate in the near future will recover to the high level of the 1970s or will stabilize at an intermediate level between the late 1980s low and the 1970s high.

The fact that growth of plaice is reduced at high levels of population density implies that an increase in the survival of pre-recruits in the plaice box will lead to a higher density and hence to a reduction in growth rate. The expected gain in recruitment due to the plaice box (5-18%; scenario D) is much less than the amplitude of recruitment variations. A strong year class is about 2-3 times the size of an average year class. Therefore, it is expected that the degree to which growth maybe reduced due to the higher density of pre-recruits is insufficient to take away the gain of an improved survival

The significant relationship between beam trawl intensity and growth rate of plaice and sole (de Veen, 1978; Rijnsdorp & van Beek, 1991a; Rijnsdorp & van Leeuwen, 1996) prompted the hypothesis that beam trawling may improve the food availability by changing the benthic

assemblage in the heavily trawled areas towards high productive small organisms. If true, the reduction in beam trawl effort in the plaice box may have led to a reduction in the feeding conditions and may have contributed to a reduction in growth. However, no time series information on the abundance of the relevant benthic organisms is available to test this hypothesis. An analysis of the abundance of eight larger benthic species caught in demersal fish surveys in the south-eastern North Sea showed changes in abundance that were significantly related to the changes in the plaice box regime as well as gradual changes over time (Piet et al., 1998).

A related aspect is that beam trawling may affect the spatial distribution of plaice by attracting the fish to the rich feeding grounds in the heavily trawled areas. Recently, fishermen reported a change in the spatial distribution of small plaice towards the border of the plaice box, which is known to be heavily trawled (Rijnsdorp et al., 1998). In a special survey conducted in 1996, van Leeuwen & Rijnsdorp (1996) observed that the discard size class was most abundant around the border of the plaice box with a predominance inside the plaice. At present the available evidence for an interaction between beam trawling, food availability and spatial distribution of plaice is indirect and at most suggestive. The hypothesis, however, needs careful further examination because it may have important consequences for the effect of area closures for trawl fisheries.

4.3 Synthesis

After the establishment of the plaice box in 1989 the yield and spawning stock biomass decreased substantially in contrast to the expectation. This phenomenon may be explained by a number of coinciding factors. First, the positive effect of the reduction in discard mortality was offset by the larger negative effect of the observed decrease in growth rate for juvenile plaice in the late 1980s and early 1990s. Second, the best estimate of the number of larvae settling in the plaice box is given by the abundance of pre-recruit plaice estimated during the autumn research vessel surveys. These data indicate a relatively low number of pre-recruit plaice in the early 1990s suggesting that a lower level of larval settlement has contributed to the decrease in yield and spawning stock biomass. Third, the ecosystem changes observed in the demersal fish and epibenthos of the eastern North Sea suggests that changes in the ecosystem that are not related to the plaice box but coincided with the establishment of the box. Fourth, the observed increase in abundance of cormorants may have raised the level of natural mortality. These factors have all contributed to the decrease in the yield and spawning stock biomass since 1989 and despite the reduction in discard mortality due to the reduction of fishing effort in the plaice box. The evidence available at present does not support that density-dependent growth will have a negative influence on the effectiveness of the plaice box. No direct evidence is available to support the hypothesis that a feedback mechanism between beam trawling and the spatial distribution and growth of plaice has negatively affected the results of the plaice box. However, further studies are required to test this hypothesis.

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Table 1

Input parameters of the simulation runs. K and Linf are the von Bertalanffy growth parameters, M is the annual natural mortality coefficient, qi is the catchability coefficient for size class i, mi is the migration rate for size class i.

M	0.10
K	0.30
Linf	47.3
q1	0.0
q2	7.47E-5
q3-4	9.96E-5
q5	9.96E-5
q6	9.96E-5
m1	0
m2	2.00E-2
m3	8.00E-2
m4	1.29E-1
m5	1.36E-1
m6	2.08E-1
effort file	eff91b.tab

Table 2

Summary of simulation runs to explore the effect of a protected area in the southeastern North Sea (plaice box). The effort distributions were taken from ICES (1994)

Code	ICES'94 Code	Run	Effort file	Management regulations
A	B	#12	eff91b	no box
B	A	#10	eff91a	box in Q2, Q3 (>300 hp)
C	E	#15	eff91e	box in Q2, Q3, Q4 (>300 hp)
D	C	#13	eff91c	box in all quarters (>300 hp)
E	D	#14	eff91d	box in all quarters, all trawlers

Table 3

Results of the 'plaice box' simulation runs ($K=0.30$) for various options of the protected area.

	A	B	C	D	E
	no box	box Q2, Q3 >300hp	box Q4 >300hp	Q2- box Q4 >300hp	Q1- full closure
Discards/R (kg)	0.039	0.036	0.033	0.032	0.023
Landings/R (kg)	0.204	0.216	0.232	0.234	0.275
SSB/R (kg)	0.314	0.343	0.404	0.412	0.544
F(2-10)	0.478	0.477	0.469	0.466	0.434
F(4-8)	0.544	0.540	0.526	0.523	0.476
%discards (n)	46%	43%	40%	39%	29%
%discards (w)	16%	14%	12%	12%	8%
%recruitment (n)	58%	61%	65%	65%	75%

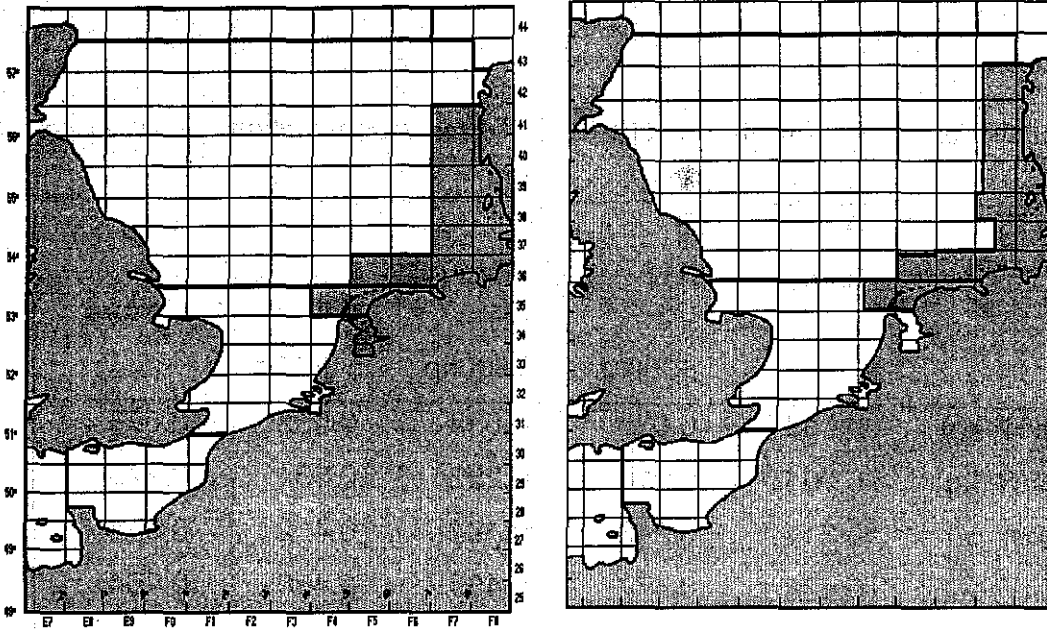


Figure 1
 Left: proposed plaice box (ICES, 1987). Right: implemented plaice box.

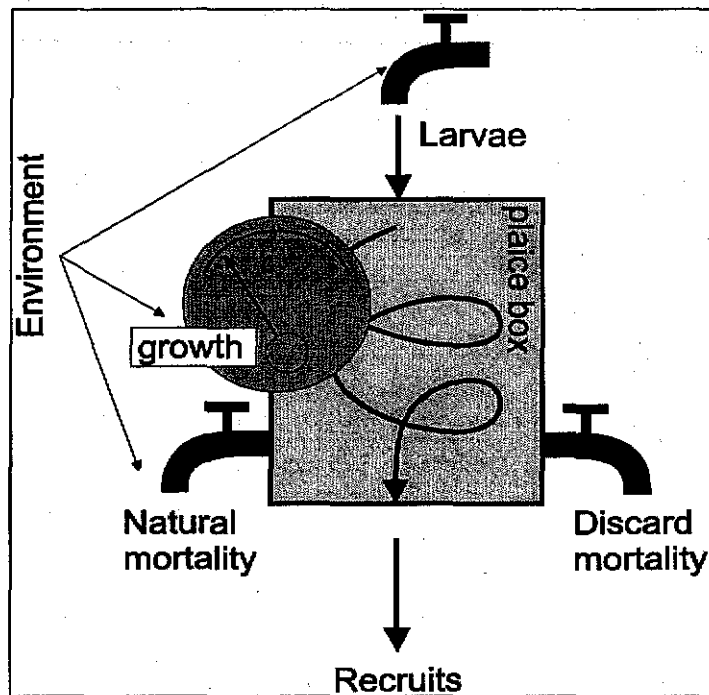


Figure 2.
 Conceptual representation of the processes affecting the survival of plaice larvae inside the plaice box. The survival determines the absolute level of recruitment to the fisheries. The eventual strength of a cohort starts with the number of larvae that survive the pelagic egg and larval phase and settle in the box. The duration of the juvenile period in the box is affected by the growth rate and during their stay in the box mortality occurs due to natural causes and fisheries (discards). The North Sea environment affects both larval input, growth rate and natural mortality rate.



Figure 3
 Subdivision of the North Sea used in the analysis:
 light coloured: plaiice box
 dark coloured: border area.

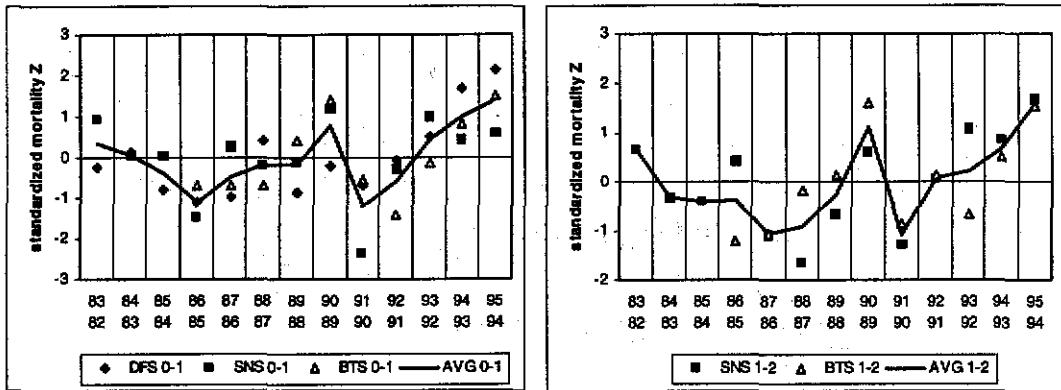


Figure 4
 Total standardized mortality rate for North Sea plaice as estimated from survey index data. Left: mortality for 0 to 1 group. Right: mortality for 1 to 2 group. The curves indicate a rise in juvenile mortality after the closure of the plaiice box. The higher mortality is unlikely to be related to the level of fishing mortality in the coastal waters. Two possible factors are: 1) the increased cormorants in North-Western Europe, which have extended their feeding areas to the Wadden Sea and the shallow coastal waters. 2) exceptionally warm conditions around the beginning of the 1990s.

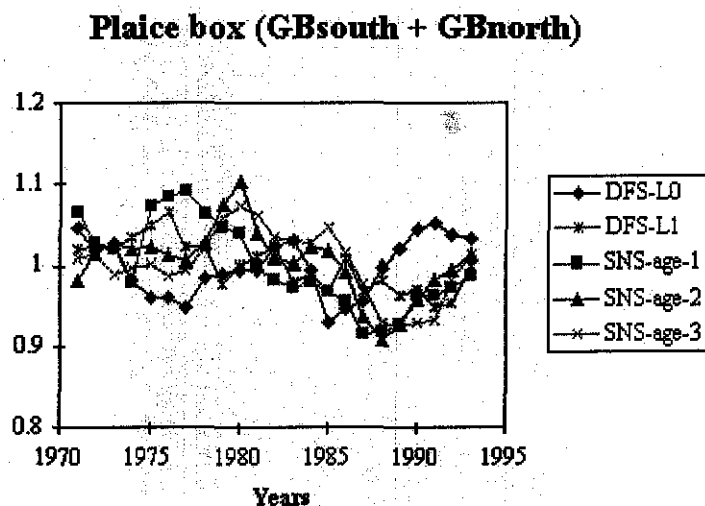


Figure 5
Changes in growth as reflected in the standardized length of 0-, 1-, 2- and 3-group in the surveys (DFS and SNS)

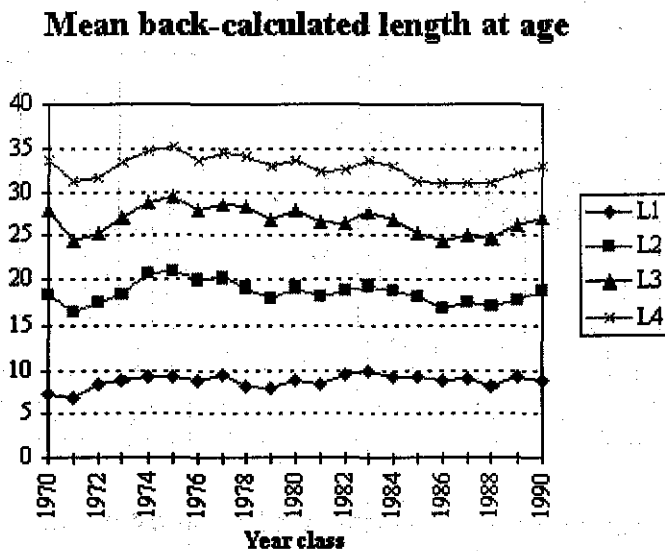


Figure 6
Changes in growth (3 year running mean) as reflected in the back-calculated length at age 1- to 4 (Rijnsdorp & van Leeuwen, 1996).

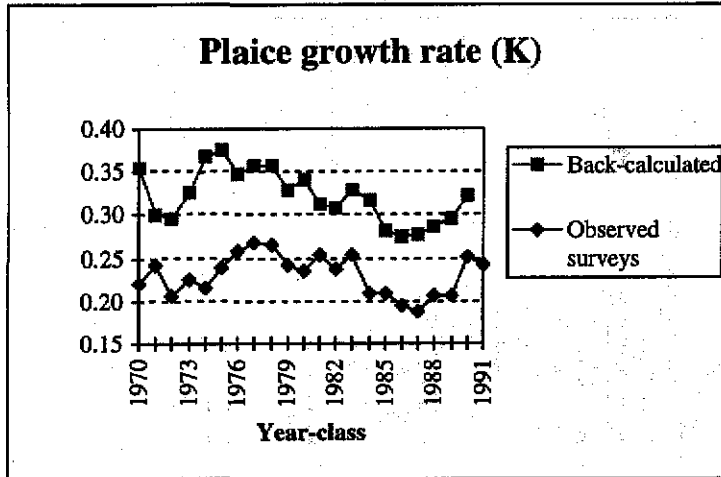


Figure 7

Growth rate (K) of individual cohorts of North Sea plaice as estimated from the mean back-calculated length and from the mean length at age 1 to 3 in the autumn surveys DFS and SNS.

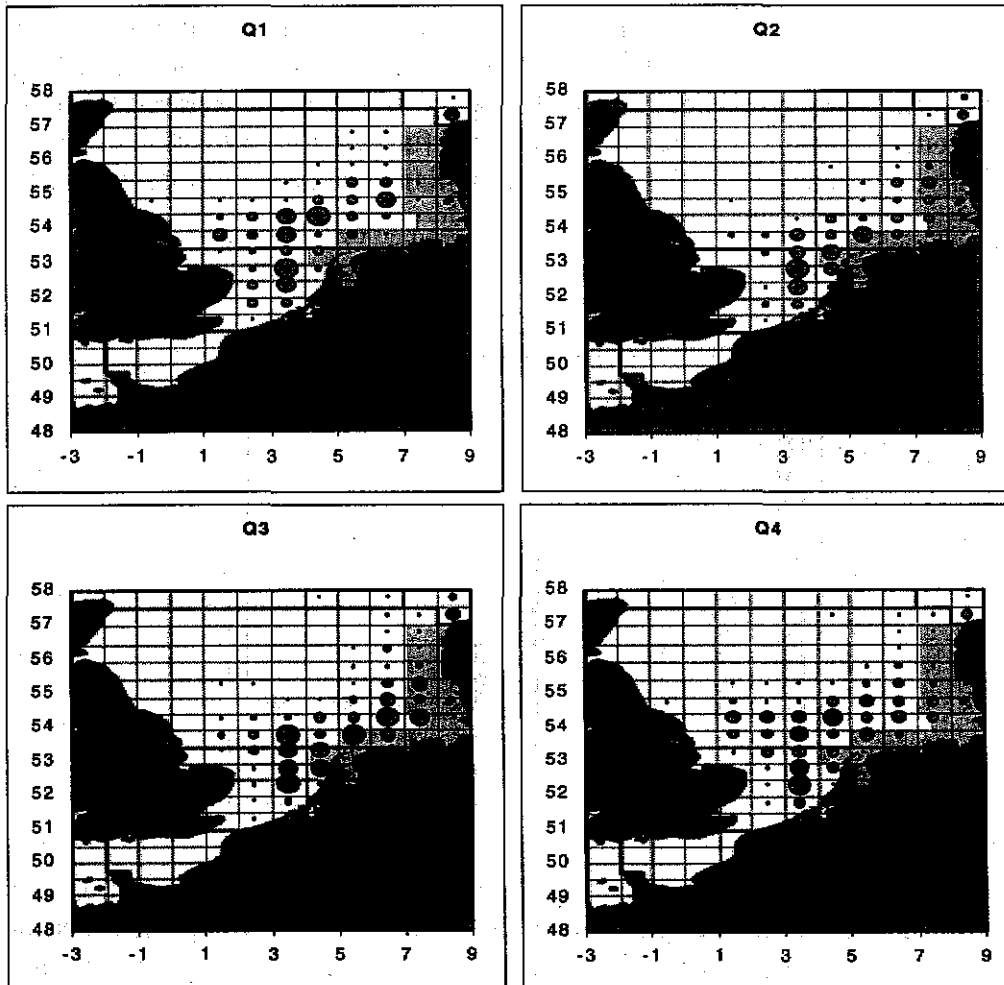


Figure 8

Relative effort distribution (NL beamtrawl fleet) 1974-1977 (ICES, 1987).

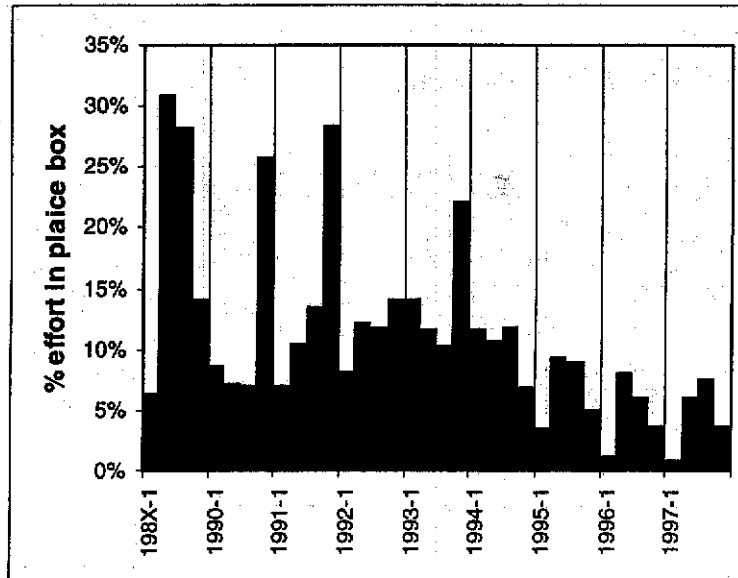


Figure 9

Proportion of fishing effort (days at sea) by quarter of the Dutch beam trawl fleet fishing in the plaice box. The 198X bars were estimated from the mid 1970s effort distribution when around 30% of the fishing effort in the 2nd and 3rd quarter was exerted in the plaice box. After the establishment of the plaice box in 1989, the larger vessels were excluded from the box in those quarters. The large vessels then re-entered the box in the fourth quarter to exploit the rich fishing grounds. In 1994 the peak in the fourth quarter disappeared due to the 4th quarter closure.

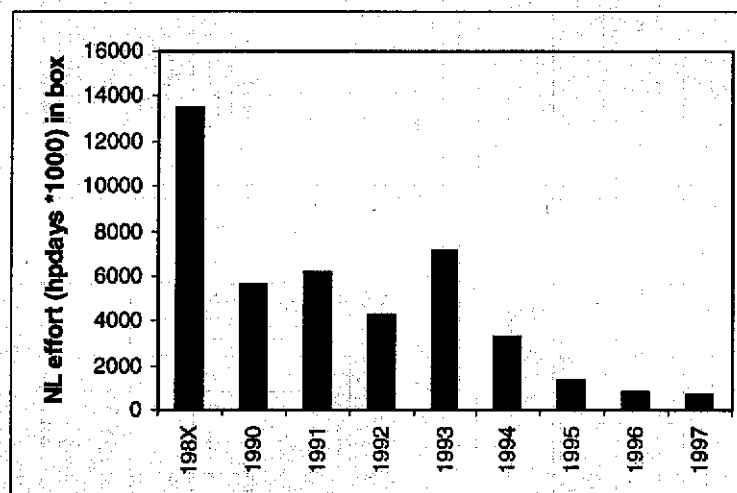


Figure 10

Fishing effort (HP-days * 1000) of the Dutch beam trawl fleet fishing in the plaice box. The 198X bar was estimated from the mid 1970s effort distribution (inside box-outside box) at the same overall level of fishing effort. Fishing effort in the first four years of the box diminished to around 40% of the pre-box level. In recent years, fishing effort in the box is only at around 6% of the pre-box levels.

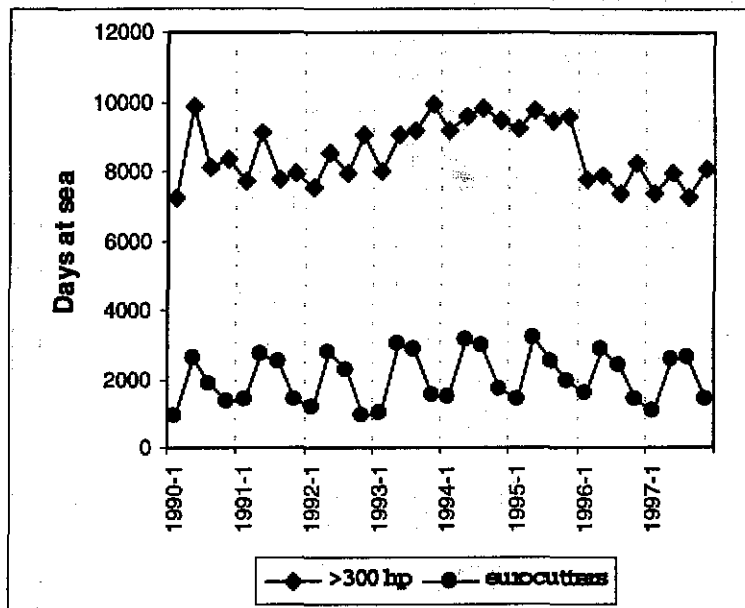


Figure 11
Total effort of Dutch beam trawl fleet (days at sea): eurocutters (225-300 hp) and large cutters (>300 hp).

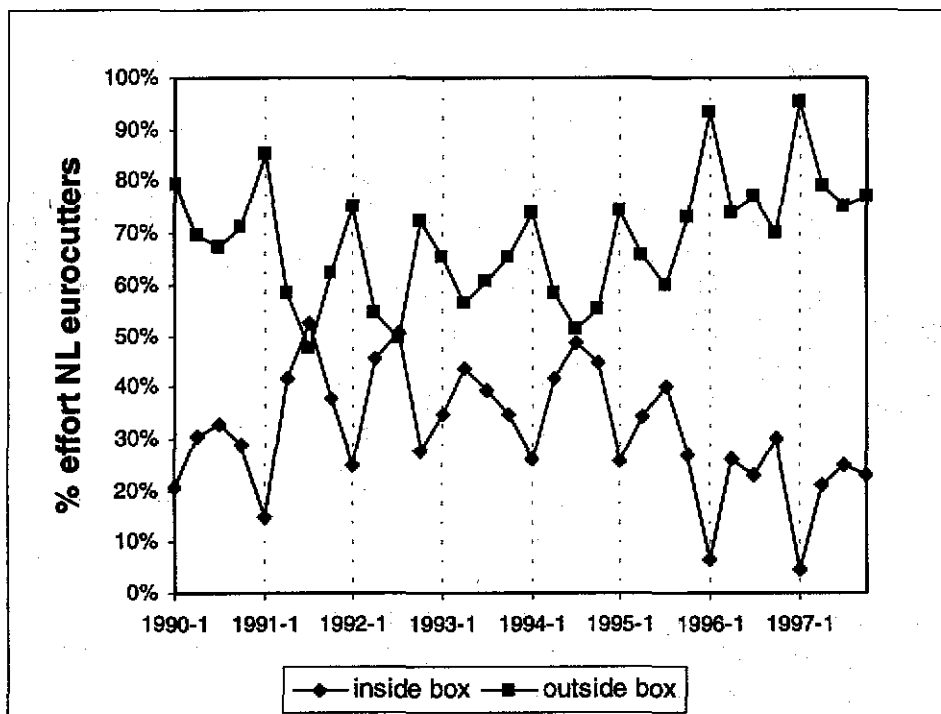


Figure 12
Proportion effort (days at sea) of the Dutch eurocutters fleet (225-300 hp) inside and outside the plaice-box.

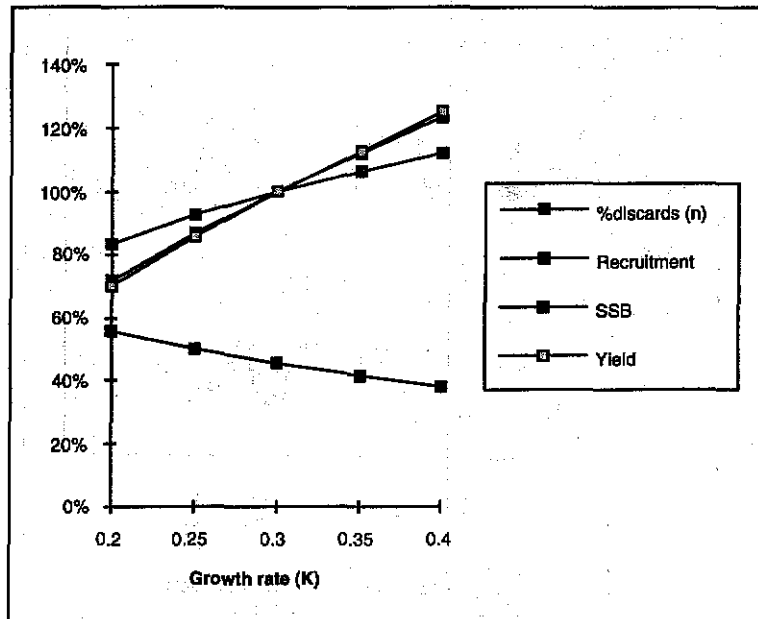


Figure 13
Effect of growth rate on the percentage discards (numbers, declining line), the level of recruitment to the fishery, the spawning stock biomass and the yield. Growth rate is expressed as the von Bertalanffy growth coefficient K. Recruitment, SSB and yield are standardized to the level at K=0.30.

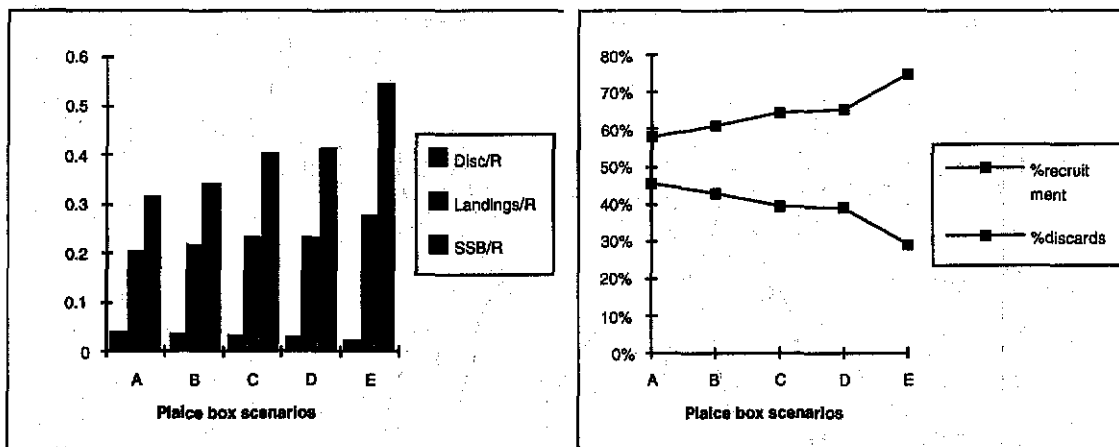


Figure 14
The effect of various scenarios of a protected area ('plaiice box') on the weight of the discards, landings, spawning stock biomass (SSB) per recruit (upper panel) and the recruitment and discard percentage (lower panel).

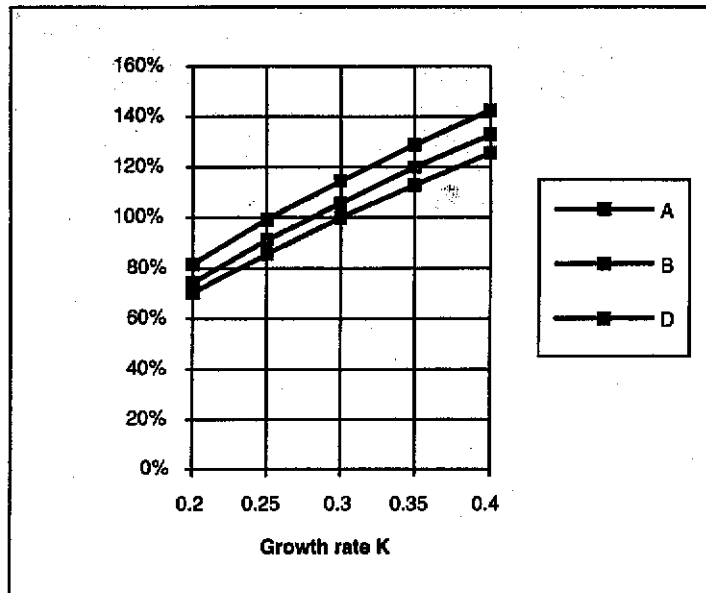


Figure 15

The effect of growth rate (K) on the simulated landings per recruit for various 'plaice box' scenarios. The change is expressed relative to the scenario without a protected area (A) at a $K=0.30$. Scenario A reflects the situation in the 1980s, scenario B the situation between 1989 - 1993 and scenario D the situation since 1994. Lines indicate from top to bottom: scenario D, B and A.

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