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Application of Mark-Recapture Experiments to Stock Assessment

Do tagging experiments tell the truth? Using electronic tags to evaluate conventional tagging data.

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ABSTRACT

For more than a century, scientists have used mark-recapture techniques as the principle means of describing the spatial dynamics of marine demersal fish species in the North Sea. Although such experiments have provided extensive datasets, the information is limited to the date and position at release and at recapture. Furthermore, these data may be biased due to the distribution of fishing effort. Recently however, electronic (archival) data storage tags (DST) have successfully been used to reconstruct the movements of free-ranging demersal fish between release and recapture. Data from DST experiments therefore, allow the calculation of fisheries independent migration parameters, and thereby provide a means of evaluating conventional tagging data. In the present study, we compared the migration patterns of North Sea plaice (*Pleuronectes platessa* L.) as inferred from a database of twentieth century tagging experiments, with data from 132 plaice tagged with DST.

INTRODUCTION

The spatial dynamics of North Sea plaice have been the subject of scrutiny for fishery scientists for more than a century. A mark-recapture technique had already been described in 1893 (Petersen 1893), and the first review on plaice tagging experiments was published in 1916 (Borley 1916). Many more tagging experiments were carried out in the 1960's and 70's, focussing mainly on spawning populations (De Veen 1962;1978; Rauck 1977), and in the 1980's, targeting juvenile plaice (ICES 1992). In total, over 50.000 North Sea plaice were tagged and recaptured in the twentieth century.

Interpretation of conventional tagging data however, must be approached within the context of the following limitations. As well as potential inaccuracy of the reported recapture position, release and recapture data provide no information with regards to the extent and directionality of movement during the intervening liberty period. The recovery of tags by commercial fishing vessels can provide insight in gross population movement. However, unless the fishing effort is homogeneously spread over the study area, the observed distribution of recoveries may reflect the commercial fleet's activity more than the true extent of fish migration (Rijnsdorp and Pastoors 1995).

Imbalance in fishing effort can be compensated for by simply using the number of recaptures per unit effort rather than the total number of recaptures, or by using a more sophisticated method as proposed by Hilborn (1990). However, any method which relates the probability of capture to the distribution of fishing effort will be dependent on the availability of accurate fishing effort data, which are frequently unavailable. Within the context of the North Sea, the Dutch beam-trawl fleet catches more plaice than any other national fleet, but reliable data on its spatial distribution were available only for the years 1990-1998 (Jennings, *et al*., 1999). Furthermore, no effort data were available to describe the fishing activity of the Belgian and French fleets, both of which play a major role in flatfish captures in the English Channel.

Despite the limitations of the data as discussed above, conventional tagging experiments have already provided significant insights into the population structure and migration patterns of North Sea plaice (De Veen 1962; 1970; 1978; Rauck 1977). However, in the absence of adequate fishing effort data, it is important to try to evaluate the accuracy of results derived from the conventional tagging database.

Experiments employing plaice tagged with electronic data storage tags (DST), also depended on the commercial fleet for retrieval of the tags. However, we were able to reconstruct the movements of these fish during their free-living period by using the data recorded by the tag (Arnold and Metcalfe 1997). Unlike recapture positions, these positional estimates, or geolocations, were independent of the spatial distribution of the fishing fleet. The experiments conducted using DST therefore allowed an effectively fisheries-independent means of calculating migration parameters, against which the migration parameters derived from conventional tagging data could be compared.

METHODS

The electronic data storage tags (DST) employed in the present study record depth and temperature. When the fish remains motionless on the sea-bed, the rise and fall of the tide is recorded. The times of high and low water and the tidal range were matched with a tidal database to identify the location of a fish. Often the recorded tidal data were not conclusive because they corresponded with different distinct regions. In all these cases depth and temperature data could be used to eliminate all but one region. The accuracy of the identified location varies between regions. The method to deduce geographic position from tidal variables is described in detail by Hunter *et al*. (in prep). A total of 1015 geolocations were available from 132 DST-tagged plaice. In order to avoid bias in the distribution of geolocations, only one geolocation per month at liberty was included per individual. This gave a final sample size of 580 geolocations. Since the geolocations were fishery-independent, it was possible to treat these as “virtual recaptures”.

The DST data were divided into 8 experiments, each corresponding to one or more of the original DST experiments. The area, period of release, and the number of individuals (recaptures) and geolocations (positions) are listed in table 1. Each DST experiment was complimented with a conventional tagging (CT) ‘experiment’. This was an extraction from the conventional tagging database, corresponding (where possible), to the DST experiment release conditions (fish length, area, months). Only plaice with a minimum total length of 35 cm were tagged with DST, so the same restriction was applied to the conventional tagging database extractions. Experiments were defined with the same release area (at the ICES rectangle level), and in all but 2 cases (exp. 3.3 & 3.6), the same release months. For the purposes of these comparisons, sex-differences were ignored. Only one of the DST-tagged plaice was male, compared with 27% of the conventionally tagged fish. The year of release was also not considered as a selection criterion. The migration range was compared for the paired experiments by mapping the geolocations (DST) and recapture positions (CT).

Furthermore, the distance travelled by DST and conventionally tagged plaice between spawning areas and feeding grounds was compared. The spawning season was defined as January to February. Geolocations within the spawning season had been obtained for only 54 DST-tagged plaice. For these individuals, the southernmost geolocation during the spawning period was defined as the spawning location. These points were treated as virtual “spawning releases”. The migration parameters of the DST spawning releases were then compared to those of CT spawning releases. Selection criteria for the CT data set were release size (>35cm) and release period (January – February). The population displacement (sea miles) and the mean distance (sea miles) in time (months at liberty) were calculated for separate spawning regions. Population displacement quantifies the distance between the release position and the centre of density of the group of tagged fish, and was calculated according to the formulae presented by Jones (1959; 1976).

RESULTS

Geographic distribution

Figures 1 - 3 show the geographic distribution of geolocations (DST) and recapture positions (CT) of the 8 paired experiments listed in table 1. Note that each recapture position (CT) corresponds to a single individual, whereas several geolocations (DST) can originate from the same fish.

All of the Southern Bight releases are shown in figure 1. The overall distribution produced by the DST and CT experiments was similar. Most plaice released in the western Southern Bight (exp. 1 and 3.4) moved along a north to north-west axis, whereas the eastern releases (exp. 3.7) generally moved north to north-east. Only 7 (4%) of the 168 CT-plaice released in the western Southern Bight (exp. 1 and 3.4) were recaptured in the eastern North Sea, 5 were recaptured in the Fisher Bank region (exp. 3.4) and 2 were recaptured off the Frisian Islands (exp. 1). None of the 31 DST-tagged fish from releases 1 and 3.4 were found to enter these areas. Note that the CT and DST tagged fish in experiment 3.4 originated from the same cruise (table 1).

Eight of the DST plaice tagged in December – January (exp. 1) moved south into the eastern English Channel (36%). This was a larger proportion than was observed with the CT fish (13%). Two individuals from release 3.4 (February) entered the eastern English Channel. These were the only two DST from this release to record all the way through to the following spawning season. Although these represent just 22% of fish in this experiment, they account for 100% of the fish which recorded data during the spawning season.

In a number of experiments in which relatively few DST were returned, but which had recorded long time-series of data, clusters of geolocations from individual fish were clearly identified. This was particularly evident from experiment 3.7 in which 4 of the 7 DST plaice recorded data over protracted time periods, yet each of these 4 fish followed clearly distinct migration pathways. This was also observed in experiment 3.4, where a single individual moved into Scottish waters, where it remained on Aberdeen Bank throughout most of it’s period at liberty (6 geolocations).

The distribution of recaptures and geolocations from the central North Sea releases (experiments 3.1, 3.3 and 3.6) are shown in figure 2. The distribution patterns observed were similar, however slight differences were observed for experiments 3.3 and 3.6, where the CT recaptures appeared to be further north than the geolocations (DST).

Results of the experiments in the German Bight (exp. 3.2), and off Flamborough (exp. 3.5 and 3.8), are presented in figure 3. Although the distributions of both CT and DST fish in the German Bight demonstrated that both groups of fish migrated into the Southern Bight, the results from the CT fish suggested a greater degree of spread to the north and to the west. The overall distribution pattern was also similar off Flamborough, although the overall range was again more extensive in CT experiments than in DST experiments.

Population displacement

The population displacement and the mean distance travelled in the 12 months following spawning are plotted in figure 4. These parameters were estimated separately for Southern Bight, Dogger Bank and German Bight spawning regions. The total number of observations and the number of observations per month at liberty are listed in figure 4. In the DST experiments each individual fish could provide more than one observation in total, but never more than one observation for every month at liberty.

Comparison between the DST and CT results showed that both population displacement and mean distance travelled were significantly different in the Southern Bight (table 2). This pattern was not observed in the German Bight or Dogger Bank regions.

Data from the DST experiments suggested that plaice spawning in the Southern Bight were migrating over substantially greater distances than fish spawning in other regions of the North Sea. The estimated population displacement 6 months after spawning varied between 80 and 120 sea miles for plaice spawning in the German Bight and Dogger Bank area, and according to the CT experiments, also for plaice spawning in the Southern Bight. The DST experiments, however, estimate a population displacement of ± 220 miles for plaice spawning in the Southern Bight.

The comparisons between DST and CT should be treated with caution however, as DST experiments were based on relatively few observations and even fewer individuals (figure 4). One of the 12 DST-tagged fish in the Southern Bight spawning group was released in the German Bight (exp. 3.2). It spawned in the Southern Bight, and within 3 months migrated ±250 miles to ±55^{o}N–7.4^{o}E, where it remained until recapture. This individual provided 9 of 37 observations (24%). If this individual was omitted from the data set, the differences between the DST and CT experiments would be much smaller, although still statistically significant.

DISCUSSION

Geographic distribution

In general we found that the range over which DST tagged fish were located and the areas from which conventionally tagged fish were returned were largely similar, especially within the range of 75% of the recaptures (or geolocations). Most of the CT experiments were based on a larger number of individuals, often drawn from several different experimental releases (f.e. releases in different years). The probability of individuals deviating from the general pattern would therefore be greater for the CT experiments, and it follows that the geographic range of recaptures will usually also be larger than the range of geolocations.

The statistical significance of differences in geographic distribution based on a contingency analysis (χ^2), depends entirely on the spatial scale employed, and is therefore essentially arbitrary. To illustrate this point: none of the CT - DST comparisons were found to differ significantly at the level of ICES divisions, however most of the experiments did differ significantly at the level of ICES rectangles.

DST results showed that approximately one third of the plaice released in the Southern Bight visited the eastern English Channel. These results are consistent with previous observations of DST tagged plaice (Arnold and Metcalfe 1997), and the observed differences between the DST and CT results may at least partially be explained by the behaviour of these fish during spawning. Plaice in the Southern Bight are known to use selective tidal stream transport to migrate, while plaice in the German Bight and central North Sea do not use this transport mechanism (Hunter 2001). This behaviour may have two implications for the present results. Firstly, tidally transporting plaice spend significantly more time off the sea-bed during migration, and may therefore be less available to capture by beam trawl during the migratory period. Secondly, DST records demonstrate that the majority of plaice reaching the eastern English Channel spawning grounds rarely remain there for longer than 6 weeks before returning to the North Sea. Although we have insufficient data at present to determine the levels of fishing effort in the eastern English Channel, it seems plausible that the low levels of recapture from this area may result from lower levels of fishing effort, possibly in combination with reduced catchability.

Results from DST experiments further illustrate the limitations of using DST data as “virtual recaptures” given the ability on occasion, to identify individual fish within the plots of geolocations. This was most pronounced in experiment 3.7 (figure 1), in which 4 individual fish, each demonstrating contrasting migration patterns, can clearly be identified from the distribution plots. The six southernmost DST plaice effectively described the extent of the observed recapture distribution of CT fish. One DST plaice migrated north of Dogger Bank Tail End, whereas no CT fish were recaptured there. This difference may also be related to bias due to fishing effort, as beam trawling effort is relatively low in the central North Sea (Jennings *et al*. 1999)

An unexpected result from release 3.4 (figure 1) was the recapture of five CT plaice from the north-eastern North Sea. These fish originated from the same tagging cruise as the DST tagged fish, none of which ever left the western North Sea. However this difference can be due to chance alone, as experiment 3.4 contained 101 CT tagged plaice, but only 9 DST tagged plaice.

The DST and CT data-sets for central North Sea fish were largely consistent, although the CT plaice from 2 of these releases (exp. 3.3 and 3.6) appeared to be distributed slightly further to the north. These differences were most probably related to differences in the release months (table 1). The DST plaice were released at the end of the feeding season (Oct.-Dec.), whereas the CT plaice were released at the beginning or middle of the feeding season (Apr.-Jul.).

DST experiments have revealed that the population structure of North Sea plaice may be related to the distribution of thermal stratification during the summer months (Hunter 2001). The DST tagged fish in experiment 3.2 appeared to have been released at the northernmost limit of their distribution. The release position was in the immediate vicinity of a transitional thermal area (the southernmost limit of the thermally stratified layer). All DST fish from release 3.2 remained in the thermally mixed zone to the south of the thermal front (figure 3). The CT datapoints from experiment 3.2 (figure 3) may have partly been derived from a more westerly release in deeper, cold stratified water. These fish would therefore belong to the same subgroup sampled by releases 3.1, 3.3 and 3.6 (figure 2). The influence of physical factors on population distribution at this scale can not be discriminated using CT data.

Population displacement

Population displacement was calculated in order to quantify any differences in overall migration patterns identified from the visual inspection of the recapture- and geolocation maps. In the case of conventional tags, spawning releases were selected and the migration parameters were calculated in relation to the release position. For DST, the movement after spawning was analysed in relation to the spawning geolocation, therefore the variable ‘months at liberty’ for these tags was really the number of months after spawning.

We found a clear difference between the two data-sets in that plaice spawning in the Southern Bight were found to migrate over greater distances according to DST data than was observed from recapture positions alone. The differences between DST and CT data were not observed for plaice spawning in the German Bight or in the Dogger Bank regions.

The Southern Bight data-set contained all DST tagged fish that spawned in the Southern Bight irrespective of release position. Plaice that were released in the Southern Bight and spawned in the eastern English Channel were not included. Therefore, our previous observation that more plaice entered the eastern English Channel according to the DST data, did not account for the differences in population displacement. The CT experiments appear to have underestimated the overall distance travelled by plaice spawning in the Southern Bight. This bias is most probably caused by the spatial distribution of fishing effort. Beam trawling effort is highest in the south-eastern North Sea (Jennings *et al*. 1999). Since these fish migrate northwards following spawning we can infer that individuals moving into the central North Sea will have a much lower probability of being captured.

Conclusions

We found that the general migration patterns of plaice observed from DST tagging experiments were largely confirmed by the results from conventional tagging data. However, subtle differences existed between the two datasets. The most evident difference was observed in the Southern Bight: our results suggest that the extent of migration from the Southern Bight may have been underestimated by conventional tagging experiments. It would appear therefore that large tag recapture data-sets can provide important information with regards to general migration patterns and population structure, but that DST data can provide more information on migration rates at a finer temporal and spatial scale. Physical data recorded by DST have further allowed the interpretation of spatial distributions, which would not otherwise have been apparent from CT data. It is concluded therefore that conventional tagging experiments “tell the truth, but not the whole truth”.

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Table 1. For each pair of conventional tag experiment (CT) and data storage tag experiment (DST): The release conditions (region, ICES rectangles, months, years), the number of individuals recaptured and the number of positions (recapture position or geolocation).

Exp.	Tag	Release				Number of	
		Region	ICES rectangles	Months	Years	Recaptures	Positions
1	DST	Southern Bight	33F2, 34F2	Dec-Jan	1993, 1996-97	22	64
	CT	Southern Bight	34F2	Dec-Jan	1959-60, 1991-95	67	67
3.1	DST	Central North Sea	41F5	Oct	1997	16	66
	CT	Central North Sea	41F5, 41F6	Oct	1997	29	29
3.2	DST	German Bight	38F6, 39F6, 39F7	Oct-Nov	1997	20	95
	CT	German Bight	38F6, 39F6, 39F7	Oct-Nov	1947, 1973, 1997-98	52	52
3.3	DST	Central North Sea	40F4, 41F4	Dec	1997	40	193
	CT	Central North Sea	40F4	May	1946-54, 1958	268	268
3.4	DST	Southern Bight	34F2	Feb	1998	9	56
	CT	Southern Bight	34F2	Feb	1998	101	101
3.5 & 3.8	DST	Dogger Bank	37F2, 38F1	Sep-Oct	1998-99	11	46
	CT	Dogger Bank	37F1, 38F1	Aug-Sep	1907, 1947, 1963	83	83
3.6	DST	Central North Sea	42F3, 43F2, 43F3	Oct	1998	7	27
	CT	Central North Sea	43F3	Apr, July	1911, 1957	35	35
3.7	DST	Southern Bight	33F3	Feb	1999	7	33
	CT	Southern Bight	33F3, 34F3	Feb	1960-61, 1972, 1975	107	107

Table 2. ANOVA table of the effect of time after spawning (months) and tag-type (DST or CT) on the estimation of population displacement and mean distance.

		Population displacement			Mean Distance		
Source	DF	SS	F	P	SS	F	P
All regions							
Error	21	4600.0			3026.7		
Sin(months)	1	17937.8	81.89	<0.001	15493.9	107.50	<0.001
Tag-type	1	344.4	1.57	0.224	1.1	0.01	0.931
Southern Bight							
Error	18	20887.2			16230.5		
Sin(months)	1	41652.2	35.89	<0.001	35073.4	38.90	<0.001
Tag-type	1	31769.1	27.38	<0.001	26060.2	28.90	<0.001
Dogger Bank							
Error	20	6520.1			4083.6		
Sin(months)	1	13953.7	42.80	<0.001	10375.1	50.81	<0.001
Tag-type	1	173.3	0.53	0.474	323.9	1.59	0.222
German Bight							
Error	20	8849.6			4815.7		
Sin(months)	1	11274.7	25.48	<0.001	9135.4	37.94	<0.001
Tag-type	1	453.4	1.02	0.324	1.9	0.01	0.931

Figure Legends

Figure 1
Geographic distribution of recaptures (CT) and geolocations (DST) for plaice released in the Southern Bight. The maps show the release positions (x) and the recapture positions or geolocations (□), further details on the experiments are listed in table 1.

Figure 2
Geographic distribution of recaptures (CT) and geolocations (DST) for plaice released in the central North Sea. The maps show the release positions (x) and the recapture positions or geolocations (□), further details on the experiments are listed in table 1.

Figure 3
Geographic distribution of recaptures (CT) and geolocations (DST) for plaice released in the German Bight and off Flamborough. The maps show the release positions (x) and the recapture positions or geolocations (□), further details on the experiments are listed in table 1.

Figure 4
Comparison of the migration parameters estimates based on data storage tag experiments (DST) and conventional tag experiments (CT). Population displacement in sea miles (A) and the mean distance (± se) in sea miles (B) in relation to months at liberty for 3 spawning regions. The number of individuals recaptured (ind.), the total number of observations (obs.) and the number of observations for each X-value are listed.

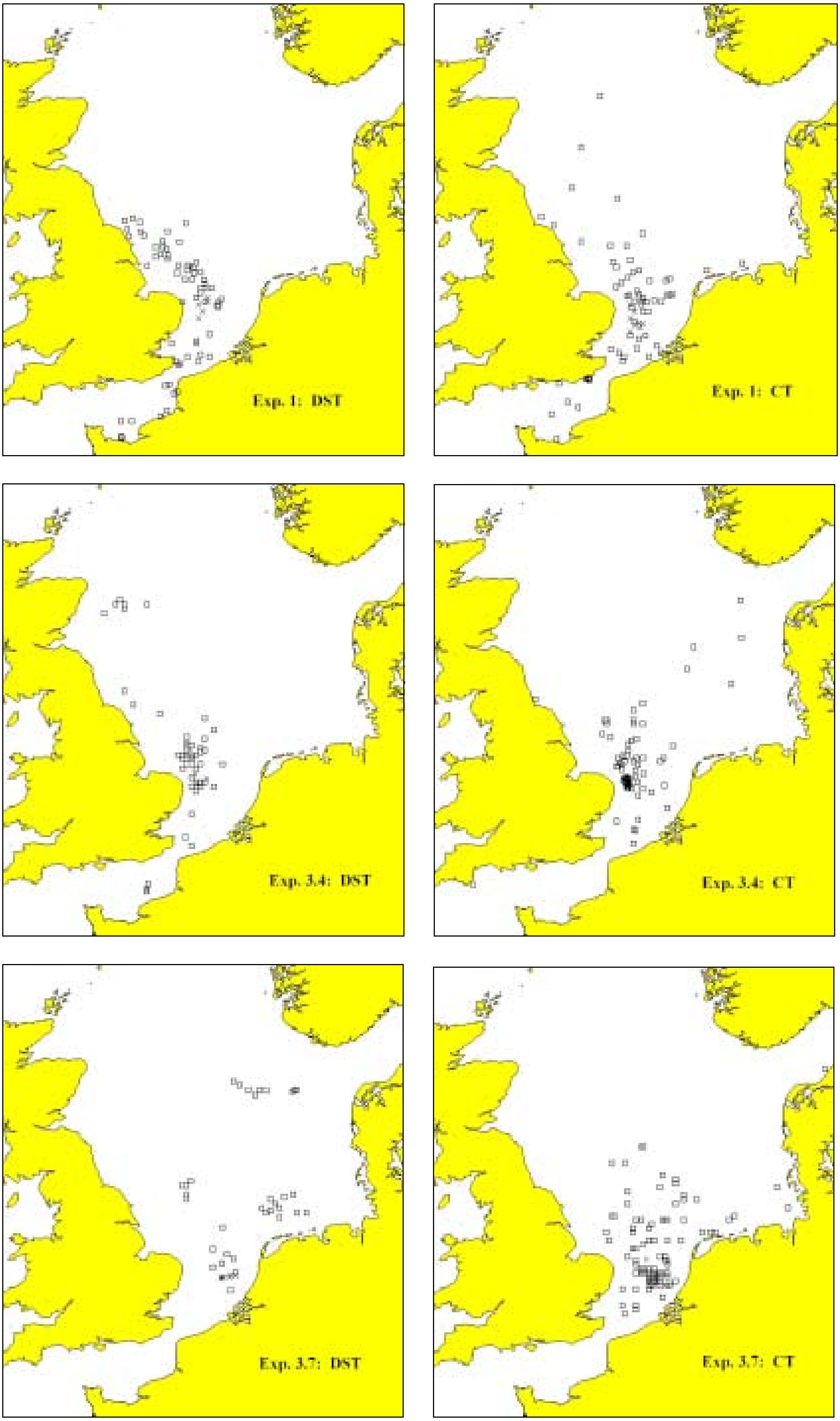


Figure 1

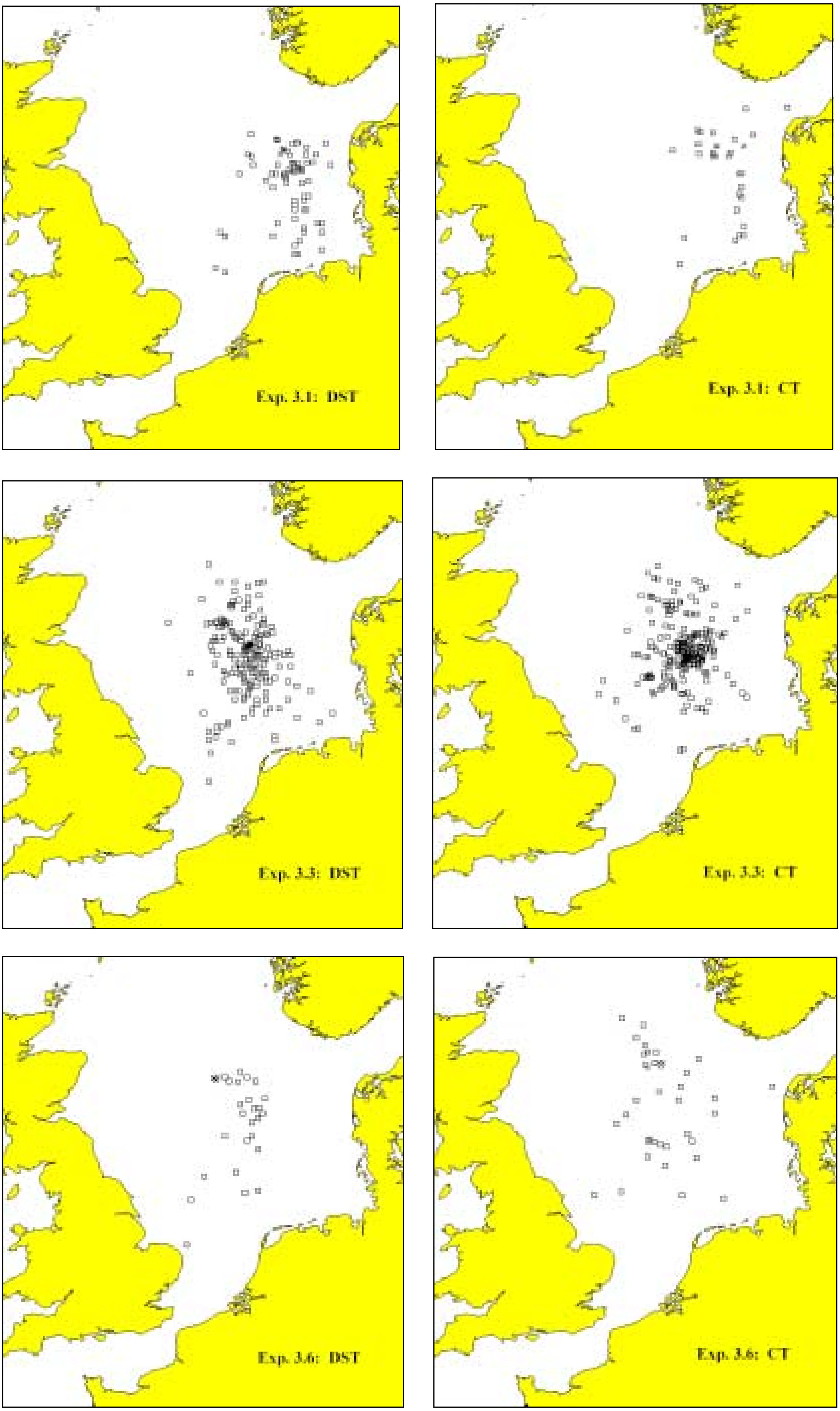


Figure 2

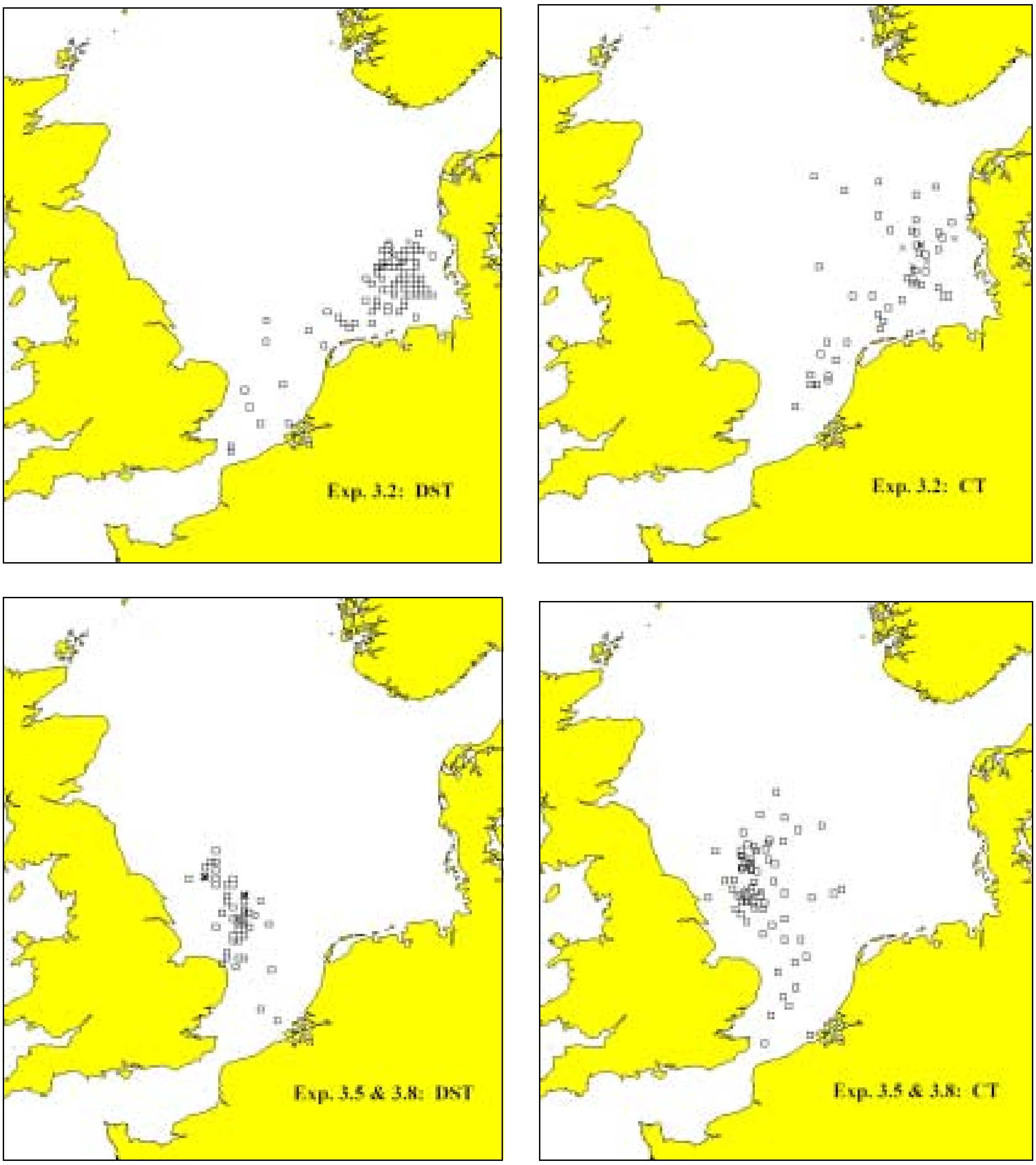
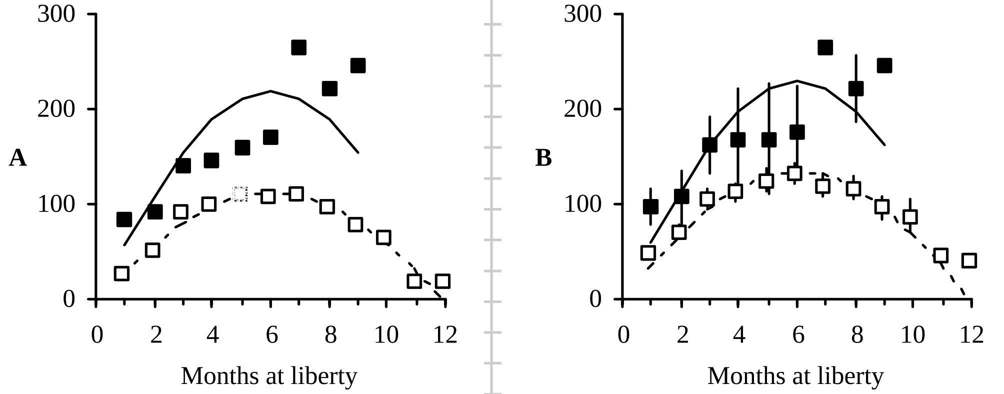


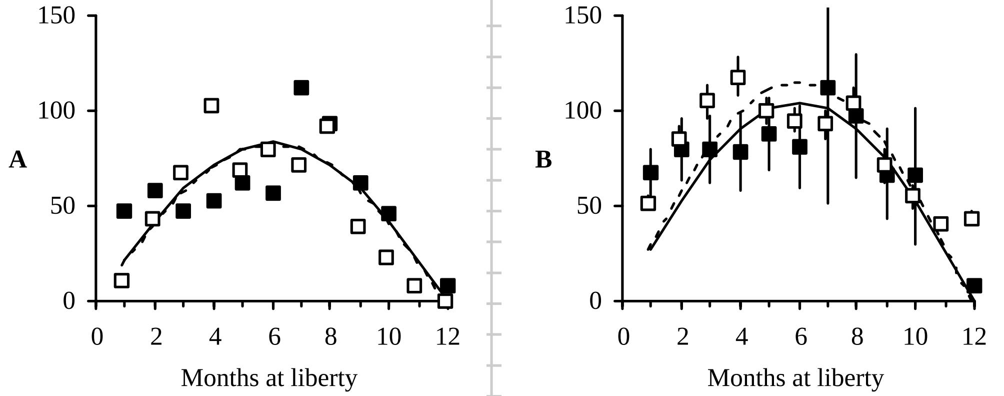
Figure 3

Southern Bight



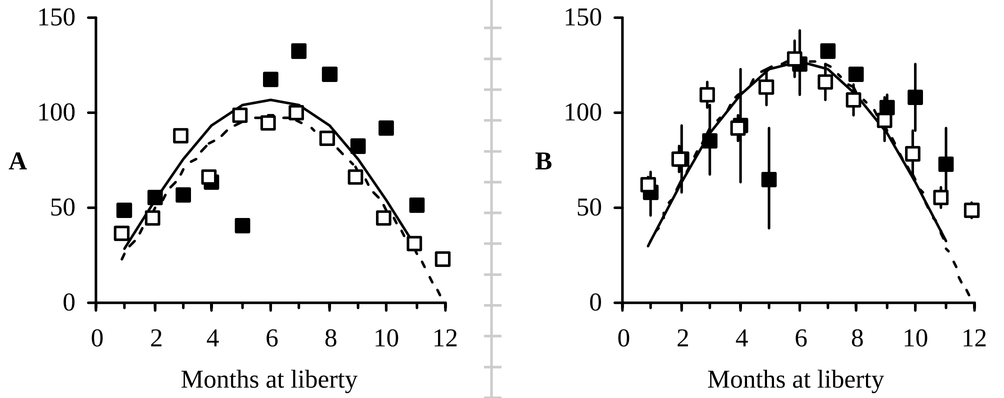
N	DST	CT
ind.	12	573
obs.	37	573
1	9	89
2	8	71
3	5	61
4	5	47
5	3	44
6	3	40
7	1	34
8	2	34
9	1	22
10		18
11		54
12		59

Dogger Bank



N	DST	CT
ind.	20	641
obs.	87	641
1	20	108
2	17	45
3	11	39
4	11	29
5	9	49
6	8	50
7	2	42
8	3	28
9	3	23
10	2	45
11		111
12	1	72

German Bight



N	DST	CT
ind.	11	505
obs.	39	505
1	9	86
2	7	62
3	6	39
4	4	48
5	3	34
6	2	21
7	1	29
8	1	31
9	2	17
10	2	25
11	2	47
12		66

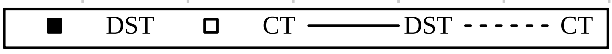


Figure 4