

Testing the effects of vessel, gear and daylight on catch data from the International Bottom Trawl Survey in the North Sea

Jacques Rivoirard

A number of vessels participate regularly to the IBTS in the North Sea. Because they survey different areas with different fish densities, the vessel effect has been investigated by selecting neighbouring trawl stations coming from each given pair of vessels. A Student test is then performed to see if the observed difference between those two vessels is significant given the variability of catches.

This analysis has been conducted for cod, haddock and herring at ages 1, 2 and 3+ for each of quarters 1 and 3 from 1991 to 1997. The most striking result is the repeated significantly different level of catches by Scotia 2 used in quarter 3 (lower for what concerns cod and haddock, but not necessarily for herring). Those systematic differences are likely to be due to the use of a gear which is different from the other vessels.

The effect of daylight on cod, haddock, whiting and herring at ages 1, 2 and 3+ in quarter 1 has been investigated by selecting neighbouring pairs of stations from the same vessel. A Student test has been performed to evaluate if catches at night are significantly different from, and for instance lower than, catches at day. The significance of the correlation of catches with sun elevation has also been assessed. By repeating the analysis for each year from 1983 to 1997, a positive effect of daylight on haddock and herring all ages and on cod 2 and 3+ has been evidenced. However, obtaining a response function on sun elevation from catch data, is, despite their number, problematic.

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1 Introduction

The International Bottom Trawl Survey (IBTS) in the North Sea is a coordinated multi-vessel survey. It has been conducted in the North Sea in the 1st quarter of the year since the mid 1960's and in the 3rd and other quarters more recently. The main objective of the IBTS is to provide recruitment estimates and tuning data for ICES (International Council for the Exploration of the Sea) assessments of several commercially important fish species. However, standard abundance indices by age group are routinely calculated in a way that does not account for differences in catchability between vessels, or in catch rates between day and night.

A number of analyses have been made on these IBTS data (see for instance those referred to in Rivoirard and Wieland, 2000). The purpose of the present analysis is to test the existence of a vessel, gear, and daylight effects in these data. This is done by comparing directly the level of catches for different species at age. However the different vessels cover different areas. Similarly, the effect of daylight, if any, is expected to be larger in the data from the North of the North Sea in winter, where the short duration of day results in a high proportion of hauls performed at night. Thus, a selection of data has to be made prior to test the differences of catches between vessels or according to daylight.

2 Material

The data used in the present study have been extracted from the ICES IBTS Database for quarter 1 in 1983-1997 and quarter 3 in 1991-1996. They include in particular age-disaggregated catches (in numbers per hour trawling), vessel, gear, shooting position, date, time of day and a day/night code. They have been complemented by the local time of day (used in the present analysis) and the sun elevation. The location of hauls is illustrated in 1991 in the example of quarter 1 (Fig. 2), and in 1996 in the example of quarter 3 (Fig. 1). There are typically 400 hauls in a quarter 1 survey, and 300 in a quarter 3 one. Species under consideration are: haddock, cod, whiting, and herring. Three age classes (1, 2, and 3+) are used for each species (for herring, the class 1, 2, or 3+ represents the number of rings, equal to age +1).

3 Effect of vessel and gear

A number of vessels participate to each survey (Table 1). The vessel effect has been investigated:

- for quarter 1 in years 1991 to 1997 on haddock and cod 2 and 3+ and on herring 1, 2 and 3+;
- for quarter 3 in years 1991 to 1996 on haddock, cod, whiting and herring 1, 2 and 3+.

Fig. 1 shows the spatial distribution of the hauls made by each vessel in the example of quarter 3 in 1996.

3.1 Selection of data from overlapping pairs of vessels

Because the different vessels do not cover the same area, the differences between their mean catch level are not significant of a vessel effect. However there are some overlappings between the areas covered by the different vessels. This has been exploited in comparing directly the catches between any pair of vessels which are “overlapping” in space. Rather than delineating the intersection between the areas covered by the two vessels, we have selected (for each quarter and each year), the closest pairs of hauls (referred to as duplicates) from the two vessels. The limit distance has been taken as 20 n.m. (increasing this would increase the number of selected hauls, but also the risk to extend this 2x2 vessels comparison to vessels that do not really overlap). Care was taken that one haul is not selected more than one time for a given pair of vessels. The number of spatially overlapping pairs of vessels is the following:

	Quarter	
	1	3
1991	16	4
1992	15	10
1993	15	9
1994	11	6
1995	10	3
1996	10	8
1997	9	
total	86	40

Overlapping is more frequent in quarter 1 than quarter 3, due to the higher number of vessels involved.

3.2 Statistical test

For each pair of overlapping vessels (and each survey), a number of duplicate hauls is then selected. However the mean difference between the catches (equal also to the mean of the differences between duplicates) can be high without being significant (e.g. due to a few number of duplicates, or to a locally high variability). It can be assumed that the continuous component of the spatial structure is the same within a duplicate, and so is filtered out from the difference of a duplicate. Moreover all the samples are different. So the differences between each duplicate can be assumed as independent. A Student t-test is then performed on these duplicate differences to see if their mean is significantly different from 0, that is, if the means for the two vessels are significantly different (while the sample values are theoretically assumed to be normally distributed, the test is known to be robust against departure from normality).

An observed mean difference is considered as significantly different from 0 at probability 95% if, under the starting hypothesis that the mean is theoretically 0, it corresponds to a probability p smaller than the risk $5\% = 1/20$. This risk represents the probability to consider the difference as significant and to reject the starting hypothesis, when in fact this is true. When the test is repeated (different pairs of vessels, different years), it is normal, if the mean is theoretically 0, to observe some results considered as significant and the risk gives their expected proportion. So, if there is no vessel effect, we should expect, on average over all years and for each species at age, $86/20$, that is about 4 significant differences in quarter 1, and $40/20 = 2$ significant differences in quarter 3.

3.3 Results

The pairs of overlapping vessels presenting differences significant at probability 95% are listed in Table 2.

In quarter 1, the number of significant differences is small (in particular there is none for haddock 3+), and generally smaller than its expected value of 4. In addition no repeatable feature is observed, except maybe the appearance of WAH2 or 3.

In quarter 3 on the contrary, the number of significant differences is high, particularly for younger cod and haddock (ages 1 and 2) and older herring (2 and 3+), though there are no

significant difference for cod 3+, and only 1 for herring 1. The most striking result concerns the nearly systematic presence of vessel SCO2 in the incriminated pairs. (This is not due to a higher representation of SCO2: considering the 40 overlapping pairs of vessels over all years for quarter 3, CIR contributes: 20 times; SCO2 and TRI2: 17 each; THA: 11, THA2, ISI and WAH2: 4 each; and WAH3: 3.)

When it is significantly different, the level of capture of SCO2 is always lower than other vessels for what concerns cod and haddock:

SCO2 < CIR in 1991 (cod 1-2), 1992 (cod 1, haddock 1-2-3+), 1993-94 (cod and haddock 1 and 2), 1995 (cod and haddock 1), 1996 (cod 2)
SCO2 < WAH2 in 1992 (cod 1, haddock 1, 2 3+)
SCO2 < TRI2 in 1991 (haddock 1-2), 1992 (cod 2, haddock 2-3+), 1995 (haddock 1-2)
SCO2 < THA2 in 1996 (cod 1)

However, for herring, while all significant differences involve SCO2, its level can be higher or lower:

SCO2 < CIR in 1992 and 1995 but > CIR in 1991 (herring 2 and 3+)
SCO2 < WAH2 in 1992 (herring 3+)
SCO2 < TRI2 in 1993 (herring 2) but > TRI2 in 1995 (herring 1 and 2)

3.4 Conclusion on vessel and gear effect

Significant differences are repeatedly observed for Scotia 2 in quarter 3. Interestingly, the gear used in the data analysed is a GOV (chalut à Grande Ouverture Verticale) in all cases, except in quarter 3 for CIR in 1991 (using a Granton Trawl) and for SCO2 (using a Dutch Herring Trawl 48 feet in 1991 and an Aberdeen 48 feet Trawl from 1992 to 1996). So a vessel effect appears when there is a difference in gear, while no vessel effect appears when using the same gear. The vessel effect appears to correspond to a gear effect.

3.5 Ratio of catches between vessels

Assuming that, due to the gear employed, a vessel effect exists for Scotia 2, ratios of catches for Scotia 2 versus all other vessels in quarter 3 have been estimated. Nearest pairs of hauls without replication between Scotia 2 and each other vessel, with limit distance 20 n.mi., have been selected. A Scotia 2 haul can have for instance 2 neighbours coming from 2 different vessels, then making two pairs and so being counted twice. For a given year, the ratio is the

ratio between the mean of Scotia 2 catches and the mean of other vessels catches, from selected pairs. For all years together, the ratio is the mean of the ratios for each year - not the ratio between the means from all pairs.

Ratios of catches between SCOTIA2 and other vessels in quarter 3:

year	pairs	Cod1	Cod2	Cod3p	Had1	Had2	Had3p	Herr1	Herr2	Herr3 p
1991	58	0.11	0.38	0.74	0.39	0.46	0.56	1.36	0.54	0.40
1992	88	0.13	0.37	1.31	0.31	0.25	0.25	0.20	0.05	0.06
1993	60	0.38	0.60	0.86	0.63	0.56	0.55	0.08	0.05	0.04
1994	50	0.28	0.37	0.61	0.37	0.35	0.48	0.25	0.12	0.06
1995	48	0.20	0.53	0.68	0.45	0.56	0.72	0.20	0.10	0.09
1996	42	0.57	0.25	0.62	0.95	0.90	0.71	0.17	0.35	0.49
all		0.28	0.42	0.80	0.52	0.51	0.54	0.38	0.20	0.19

4 Effect of daylight

In the present analysis, daylight for each haul is accessible indirectly through the day-night code, the local time of day, and the sun elevation. Hauls are preferentially performed at day, but in winter days are short and a number of hauls are at night (essentially in the North of the North Sea), thus spanning a large range of daylight. The portion of N-hauls, as well as their location, vary with year, and so a postulated daylight effect is likely to bias unevenly the survey based abundance indices.

In the present analysis, the effect of daylight has been investigated on the IBTS data from quarter 1, years 1983-1997, for haddock, cod, whiting and herring 1, 2 and 3+.

4.1 Selection of data

Because N-hauls are not located evenly within the North Sea, they are not directly comparable to D-hauls. To span D/N conditions under otherwise similar conditions, hauls have been selected to include if possible each N-haul as well as the closest D-haul from the same year, same vessel, and at distance less than a given limit. The number of selected hauls varies with this limit distance as follows:

10 20 30 40 50 60 70 nm.

72 610 1342 1540 1560 1560 1560

As each N-haul and its close D-haul both belong to the area covered by the same vessel, a rather large limit of 50 nm has been selected, ensuring also to include a high number of data (780 out of a total of 1003 N-hauls in quarter 1 are then selected, those far from a D-haul are not). Such selected hauls are visualized in Fig. 2 in the example of 1991. The majority are in the Northern part of North Sea, however there are also a number of these along the German coast in 1983-1987 and 1989. Only a few are in Skagerrak and Kattegat, where cod can be abundant.

On the contrary to the analysis of the vessel effect (where the selected data were paired, in fact only the difference of each duplicate was used in the test), the data selected here have not been paired for tests and are used as a single set to analyse the effect of D/N as well as this of time of day and sun elevation. Because the existence of a spatial structure (see for instance Rivoirard and Wieland, 2000), such data are not independent but their degree of dependence is low considering the amplitude of nugget effect or short component in the variogram.

4.2 Day/Night effect

The ratio between the mean catch of night hauls and this of day hauls, plotted for each species at age through years, appears to be frequently less than 1 (Fig. 3). However such results are based on a limited number of data, often with a high variability. A Student test has been used to determine where the N-mean is significantly different from (and then for instance lower than) D-mean (the test assumes that the data are independent and that D-data and N-data are normal with the same variance, but it is known to be robust against departure from normality).

We start from the hypothesis $H_0: n = d$ (N-mean = D-mean, i.e. no effect), and reject it when the difference between the observed means is too large, i.e. corresponds to a probability p too small compared to a given risk (taken here as $2/15 = 0.133$). So if $p < 2/15$, H_0 is to be rejected (the risk is the probability to reject H_0 although H_0 is valid). Then according to whether $n < d$ or $n > d$, the hypothesis $H_1: n < d$ or $H_{-1}: n > d$ is to be preferred.

Detailed results are listed in Table 3, in the example of haddock age 2 (see also Fig. 3 for a proportional representation of the $1-p$ values).

If H_0 is true, it should be rejected *on average* (but not necessarily exactly) for 2 years out of 15, and each of H_1 and H^{-1} preferred for 1 year. This has led us to adopt, for a given species at age, the hypothesis H_0 , H_1 , or H^{-1} appearing in an excessive number of years compared to expected, and considering also all years together.

Such summarized results are listed in Table 4. A D/N effect (H_1 : $n < d$) is evidenced for haddock and herring all ages, cod 2 and 3+. In other cases, H_0 ($n = d$, no effect) is not rejected.

4.3 Effect of time of day and sun elevation

The response of catches on time of day and sun elevation has firstly been searched by plotting the experimental regressions. However no clear quantified relation appears, even in the best cases like haddock age 2 (Fig. 4 and 5) and even when considering all years together (Fig. 6).

The relation of sun elevation on time of day can be reasonably well represented by a cosine function centered at noon (Fig. 7). As a consequence, a cosine response of catches on time would closely correspond to a linear response on sun elevation. While sun elevation makes a better distinction between day and night than time of day does, its value at noon decreases with latitude and increases during winter. A question like whether the supposedly maximal level of catches at noon varies or not with sun elevation, e.g. with the julian day, while it may be important in the view of correcting catches from a daylight effect, seems out of range from the data.

While the response function of catches to sun elevation is difficult to quantify, we have tested the dependence by determining whether the correlation is significantly different from 0 (and for instance is > 0). The correlation r measures the strength of the linear dependency, more exactly the strength of the linear part of dependency. In our case, the dependency is not necessarily linear, but it is expected to be monotonic with a positive correlation, if an effect exists.

We start from the hypothesis H_0 : $r = 0$ (no effect). Then, when the number n of independent samples is large enough (> 30 ; in our case there are about 100 selected samples each year, although not necessarily independent), the estimated correlation r^* is normally distributed

with mean 0 and variance $1/(n-1)$. H_0 is to be rejected when r^* deviates too much from 0, i.e. corresponds to a too small probability. We will consider a risk of $2/15$, that is, $1/15$ for each sign of correlation. Hypothesis $H_1: r > 0$ is to be preferred when $r^* > 1.5011/\sqrt{(n-1)}$, since the probability of this event under H_0 is $P(r^* > 1.5011/\sqrt{(n-1)}) = 1/15 = 0.067$. Similarly $H_1: r < 0$ is to be preferred if $r^* < -1.5011/\sqrt{(n-1)}$. *On average, if H_0 is true*, it should then be rejected for 2 years out of 15, and each of H_1 and H_1 preferred for 1 year.

Table 5 gives the detailed results in the example of haddock age 2, while summarized results are listed in Table 6.

These results match those on N- and D-means. The correlation is significantly positive where the N-mean is significantly lower than D-mean, that is, for haddock and herring all ages, cod 2 and 3+. No significant effect is evidenced in other cases (except maybe H-1, a negative correlation of cod1 with sun elevation).

4.4 Conclusion of tests on daylight effect

An effect of daylight (catch level lower at night, positive correlation between catch and sun elevation) is evidenced for haddock and herring all ages, cod 2 and 3+. No effect is visible for cod 1 and for whiting all ages.

Acknowledgements

The European Union provided financial support (DG XIV study N° 97/0009, MIQES – The use of multivariate data for improving the quality of survey-based stock estimation in the North Sea).

Reference

Rivoirard J. and Wieland K., 2000. Correcting daylight effect in the estimation of fish abundance using kriging with external drift, with an application to juvenile haddock in North Sea. ICES CM 2000/K: 31

Table 1: List of vessels participating to IBTS, with their code in the present analysis and their year of use in quarters 1 (1991-1997) and 3 (1991-1996).

ARG = Argos
DAN2 = Dana (new)
ISI = Isis
JHJ = Johan Hjort (new)
SCO2 = Scotia (new)
THA = Thalassa
TRI2 = Tridens (new)
WAH2 = Walther Herwig
GOS = G.O. Sars
SOL = Solea
MIC = Michael Sars
WAH3 = Walther Herwig III
THA2 = Thalassa (new)
CIR = Cirolana
JOH = Johan Hjort (old)

quarter 1

ARG DAN2 83-97
SCO2 85-97
TRI2 91-97
THA 83-96 THA2 97
WAH2 87-93 WAH3 94-97
MIC 93 95-97
ISI 84-87 89-91 93
GOS 92&94
JHJ 91
SOL 92

quarter 3

ARG CIR SCO2 TRI2 91-96
ISI 91&93
THA 92-94
THA2 96
WAH2 92
WAH3 96

Table 2: Pairs of overlapping vessels with difference in mean catch significant at probability 95% (see details in text). The number of pairs of hauls considered and the ratio between the mean catch of the 1st vessel on this on the 2nd vessel are indicated.

Quarter	Species at age	year	Nb pairs	Ratio	1 st vessel	2 nd vessel
1	cod 2	1991	34	0.57	SCO2	WAH2
1	cod 2	1996	15	0.25	TRI2	DAN2
1	cod 2	1997	33	0.5	WAH3	MIC
1	cod 3+	1992	3	0.21	WAH2	TRI2
1	cod 3+	1995	26	0.54	MIC	WAH3
1	cod 3+	1995	17	0.43	WAH3	SCO2
1	cod 3+	1997	33	0.41	WAH3	MIC
1	haddock 2	1996	23	0.53	SCO2	WAH3
1	herring 1	1993	15	0.29	THA	DAN2
1	herring 1	1996	12	0.17	THA	DAN2
1	herring 2	1991	14	0.26	DAN2	WAH2
1	herring 2	1994	35	0.099	SCO2	WAH3
1	herring 2	1995	2	0.037	THA	WAH3
1	herring 2	1997	21	0.39	TRI2	THA2
1	herring 3+	1992	11	0.18	GOS	SCO2
3	cod 1	1991	38	0.08	SCO2	CIR
3	cod 1	1992	36	0.15	SCO2	CIR
3	cod 1	1992	34	0.12	SCO2	WAH2
3	cod 1	1992	12	0.6	THA	TRI2
3	cod 1	1993	34	0.23	SCO2	CIR
3	cod 1	1994	32	0.34	SCO2	CIR
3	cod 1	1995	33	0.28	SCO2	CIR
3	cod 1	1996	4	0.17	SCO2	THA2
3	cod 2	1991	38	0.52	SCO2	CIR
3	cod 2	1992	14	0.31	SCO2	TRI2
3	cod 2	1993	34	0.49	SCO2	CIR
3	cod 2	1994	32	0.59	SCO2	CIR
3	cod 2	1996	32	0.27	SCO2	CIR
3	haddock 1	1991	21	0.26	SCO2	TRI2
3	haddock 1	1992	36	0.43	SCO2	CIR
3	haddock 1	1992	33	0.45	CIR	WAH2
3	haddock 1	1992	34	0.21	SCO2	WAH2
3	haddock 1	1993	34	0.62	SCO2	CIR

3	haddock 1	1994	32	0.49	SCO2	CIR
3	haddock 1	1995	33	0.58	SCO2	CIR
3	haddock 1	1995	8	0.36	CIR	TRI2
3	haddock 1	1995	12	0.31	SCO2	TRI2
3	haddock 2	1991	21	0.35	SCO2	TRI2
3	haddock 2	1992	36	0.23	SCO2	CIR
3	haddock 2	1992	14	0.32	SCO2	TRI2
3	haddock 2	1992	34	0.23	SCO2	WAH2
3	haddock 2	1993	34	0.6	SCO2	CIR
3	haddock 2	1994	32	0.61	SCO2	CIR
3	haddock 2	1995	12	0.63	SCO2	TRI2
3	haddock 3+	1992	36	0.18	SCO2	CIR
3	haddock 3+	1992	14	0.32	SCO2	TRI2
3	haddock 3+	1992	34	0.3	SCO2	WAH2
3	herring 1	1995	12	0.051	TRI2	SCO2
3	herring 2	1991	38	0.62	CIR	SCO2
3	herring 2	1992	36	0.07	SCO2	CIR
3	herring 2	1993	21	0.046	SCO2	TRI2
3	herring 2	1995	33	0.068	SCO2	CIR
3	herring 2	1995	12	0.021	TRI2	SCO2
3	herring 3+	1991	38	0.55	CIR	SCO2
3	herring 3+	1992	36	0.053	SCO2	CIR
3	herring 3+	1992	34	0.043	SCO2	WAH2
3	herring 3+	1995	33	0.057	SCO2	CIR

Table 3: Day/night effect in the example of haddock age 2. Student test at risk 2/15 for Day-mean and Night-mean:

n/d = ratio between Night-mean and Day-mean;

p = corresponding probability if no effect;

H = resulting hypothesis;

$H = 0$ ($n = d$) if $p > 2/15 = 0.133$;

$H = 1$ ($n < d$) if $p < 2/15$ and $n < d$;

$H = -1$ ($n > d$) if $p < 2/15$ and $n > d$.

	n/d	p	H
1983	0.64	0.14	0
1984	0.46	0.11	1
1985	0.39	0.01	1
1986	0.81	0.59	0
1987	0.87	0.7	0
1988	0.62	0.21	0
1989	0.8	0.5	0
1990	0.21	0.02	1
1991	0.29	0.01	1
1992	1.22	0.64	0
1993	1.13	0.72	0
1994	0.63	0.3	0
1995	0.6	0.2	0
1996	0.82	0.49	0
1997	0.6	0.32	0
All years together	0.67	0	1

Table 4: Day/night effect. Testing $H1$ ($n < d$, i.e. Night mean < Day mean) and $H-1$ ($n > d$) under H_0 ($n = d$). Number of years for each hypothesis ("all" means "all years together").

Species	age	H_0	$H1$	$H-1$	conclusion
Expected		13	1	1	
Haddock	1	7	8+all	0	$H1$
	2	11	4+all	0	$H1$
	3+	8	7+all	0	$H1$
Cod	1	14+all	1	0	$H0$
	2	11+all	4	0	$H1$
	3+	11	3+all	1	$H1$
Whiting	1	15+all	0	0	$H0$
	2	11+all	3	1	$H0$
	3+	15+all	0	0	$H0$
Herring	1	14	1+all	0	$H1$
	2	13	2+all	0	$H1$
	3+	12	3+all	0	$H1$

Table 5: Test of correlation of catches with sun elevation in the example of haddock age 2:

Corl = correlation;

Limit = absolute limit value for significance at risk 2/15;

H = resulting hypothesis:

H = 0 for correlation not significantly different from 0;

H = 1 for correlation significantly > 0;

H = -1 for correlation significantly < 0.

	corl	limit	H
1983	0.12	0.14	0
1984	0.17	0.15	1
1985	0.21	0.12	1
1986	0.08	0.15	0
1987	0.09	0.14	0
1988	0.09	0.16	0
1989	0.07	0.14	0
1990	0.31	0.18	1
1991	0.29	0.16	1
1992	-0.07	0.15	0
1993	-0.16	0.15	-1
1994	0.1	0.17	0
1995	0.09	0.16	0
1996	0.07	0.15	0
1997	0.04	0.14	0
all	0.08	0.04	1

Table 6: Correlation of catches with sun elevation. Testing H1 ($r > 0$) and H-1 ($r < 0$) under Ho ($r = 0$) for correlation r between catch and sun elevation.

Species	age	Ho	H1	H-1	conclusion
Expected		13	1	1	
Haddock	1	8	7+all	0	H1
	2	10	4+all	1	H1
	3+	9	6+all	0	H1
Cod	1	10	2	3+all	H0
	2	10+all	4	1	H1
	3+	12	3+all	0	H1
Whiting	1	14+all	0	1	H0
	2	11+all	2	2	H0
	3+	13+all	1	1	H0
Herring	1	11	4+all	0	H1
	2	13+all	2	0	H1
	3+	11	4+all	0	H1

1996 quarter 3

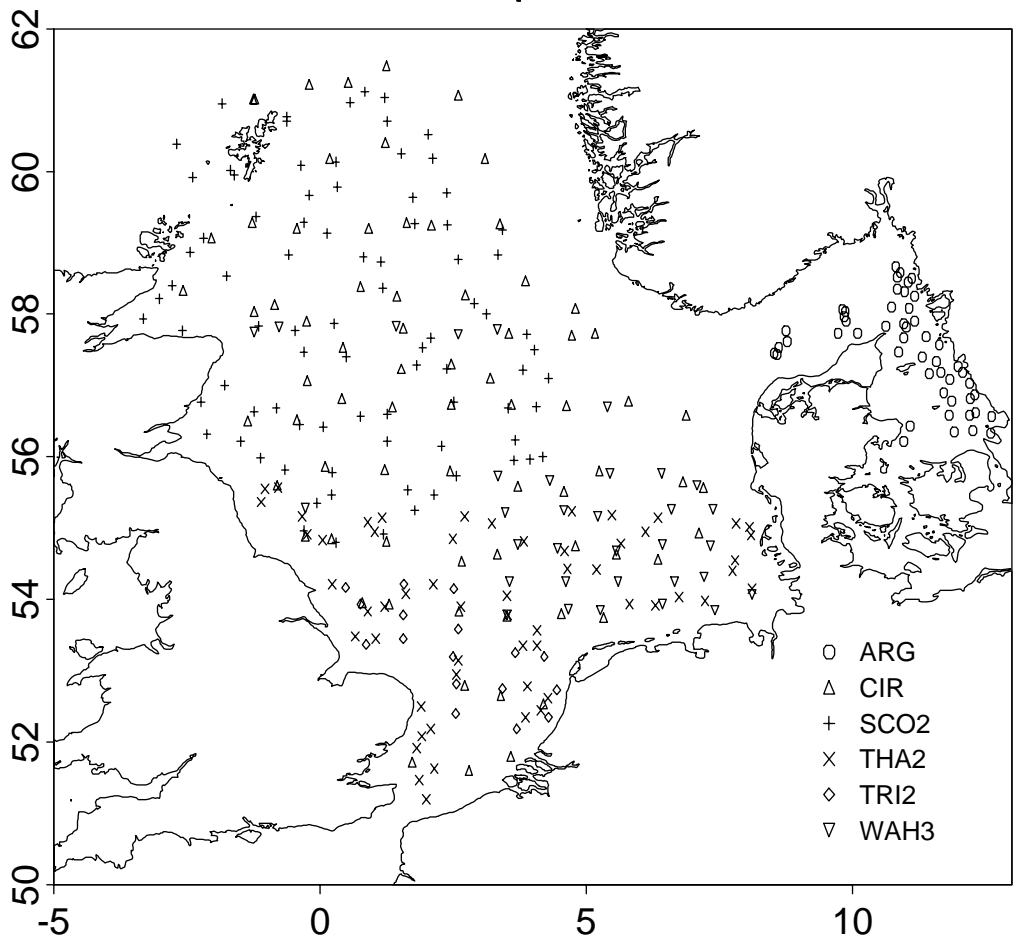
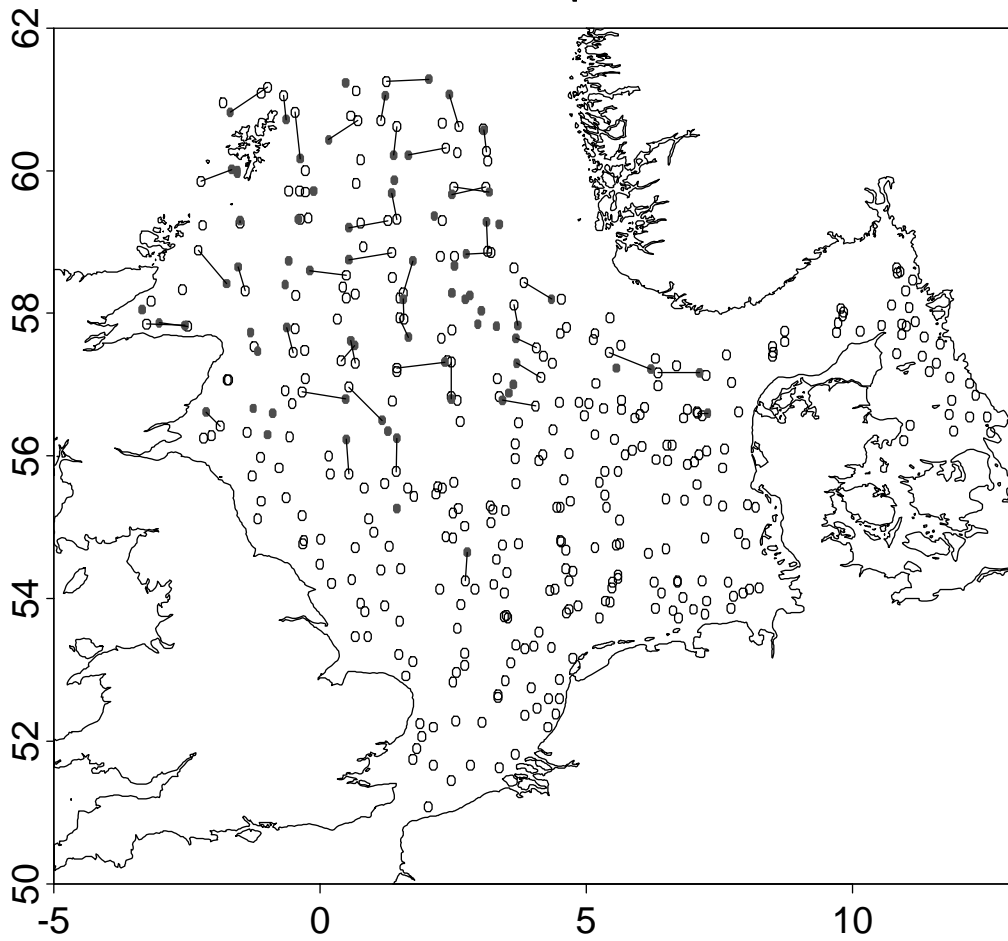


Fig. 1: Location of trawl stations and vessels in the example of quarter 3, 1996

IBTS 1991 quarter 1



pairs of close day/night samples from same vessel

Fig. 2: Locations of hauls in the example of quarter 1, 1991: day-hauls (open circles); night-hauls (black circles); lines between close pairs of night and day hauls from same vessel.

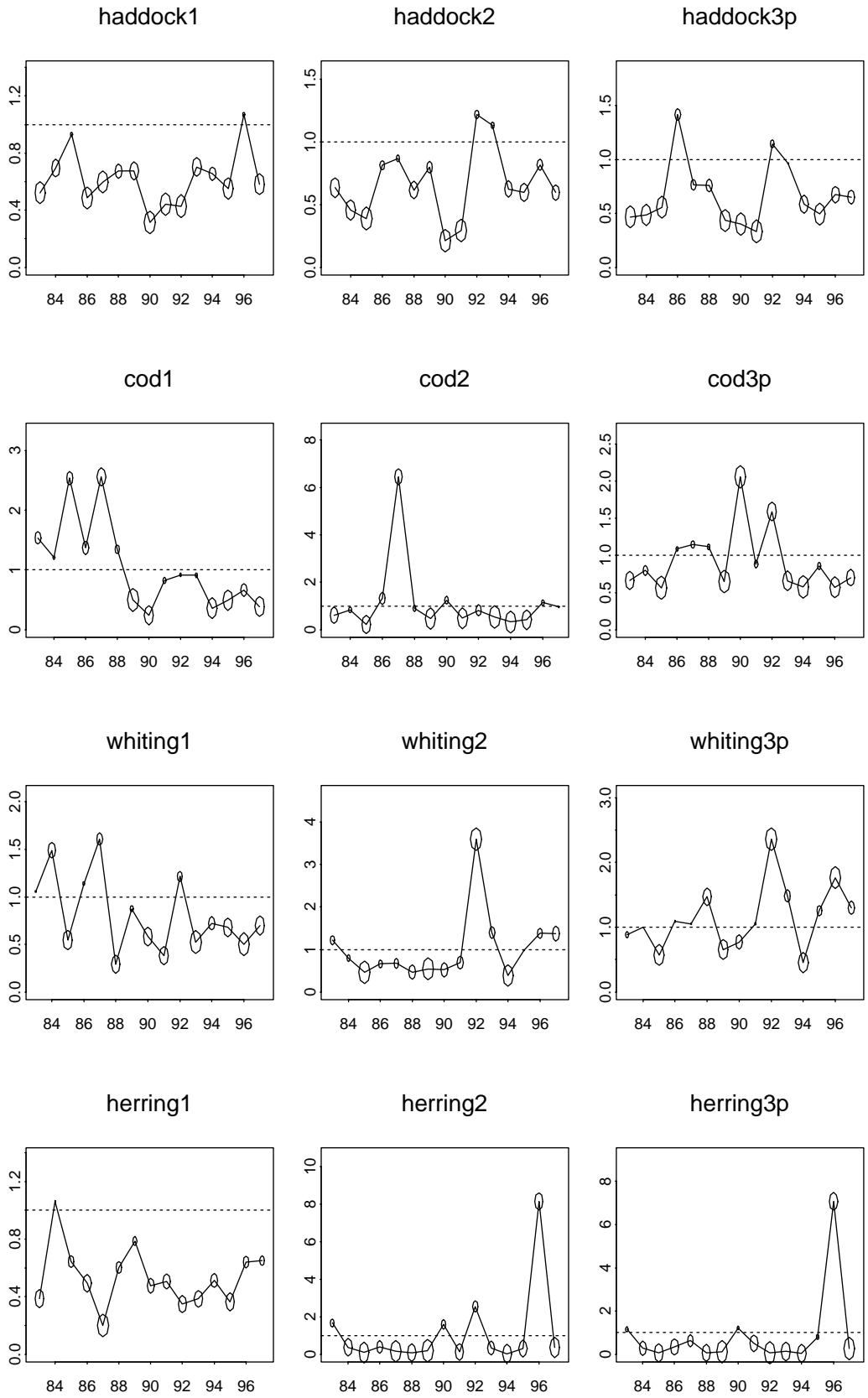


Fig. 3: Ratios between mean of night catches and mean of day catches plotted through years for the different species at age in quarter 1. Symbols are proportional to $1-p$ (see details in text): the larger the symbol, the more significantly different from 0 the difference in means.

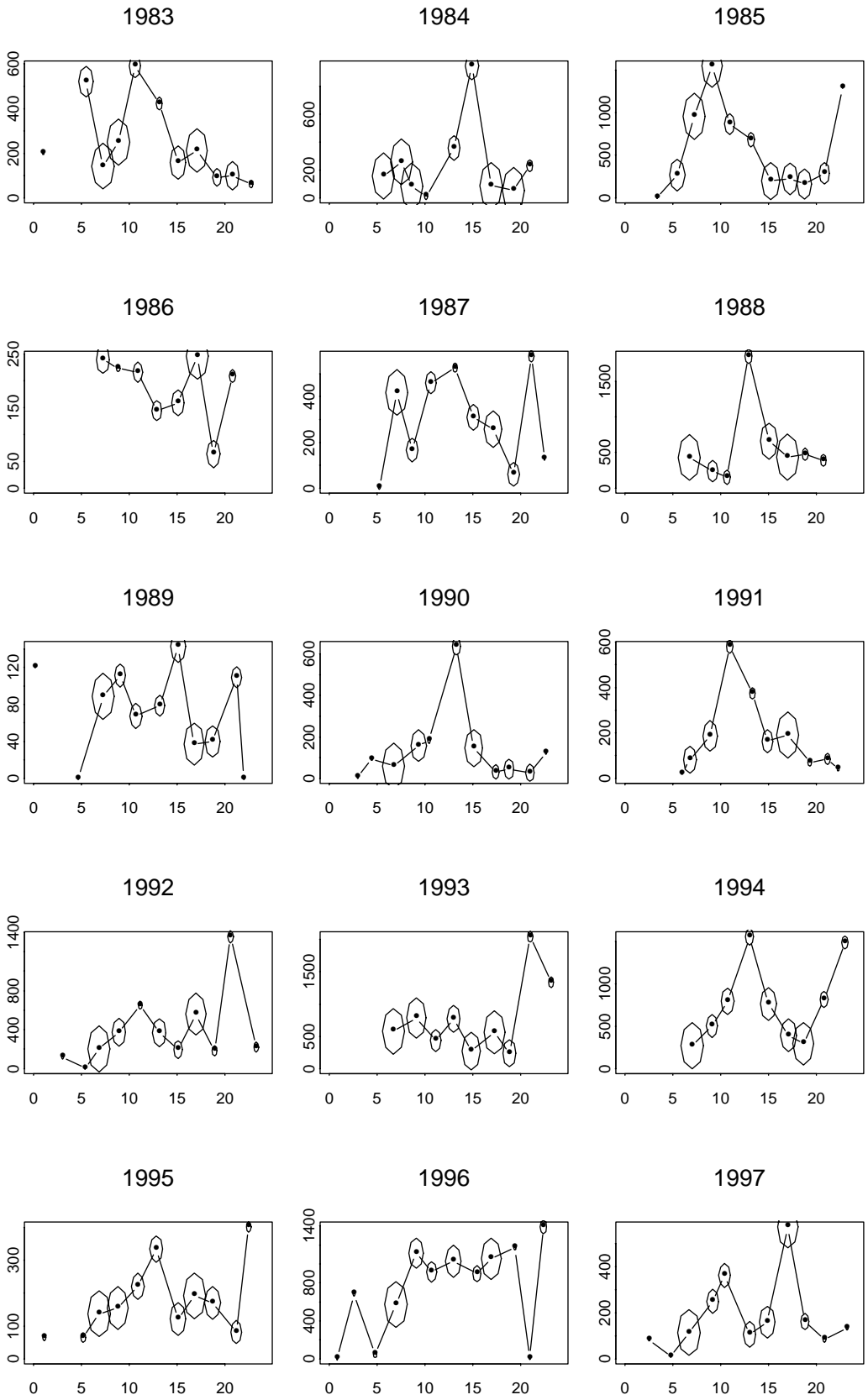


Fig. 4: Experimental regression of catches on time of day through years in quarter 1, in the example of haddock 2.

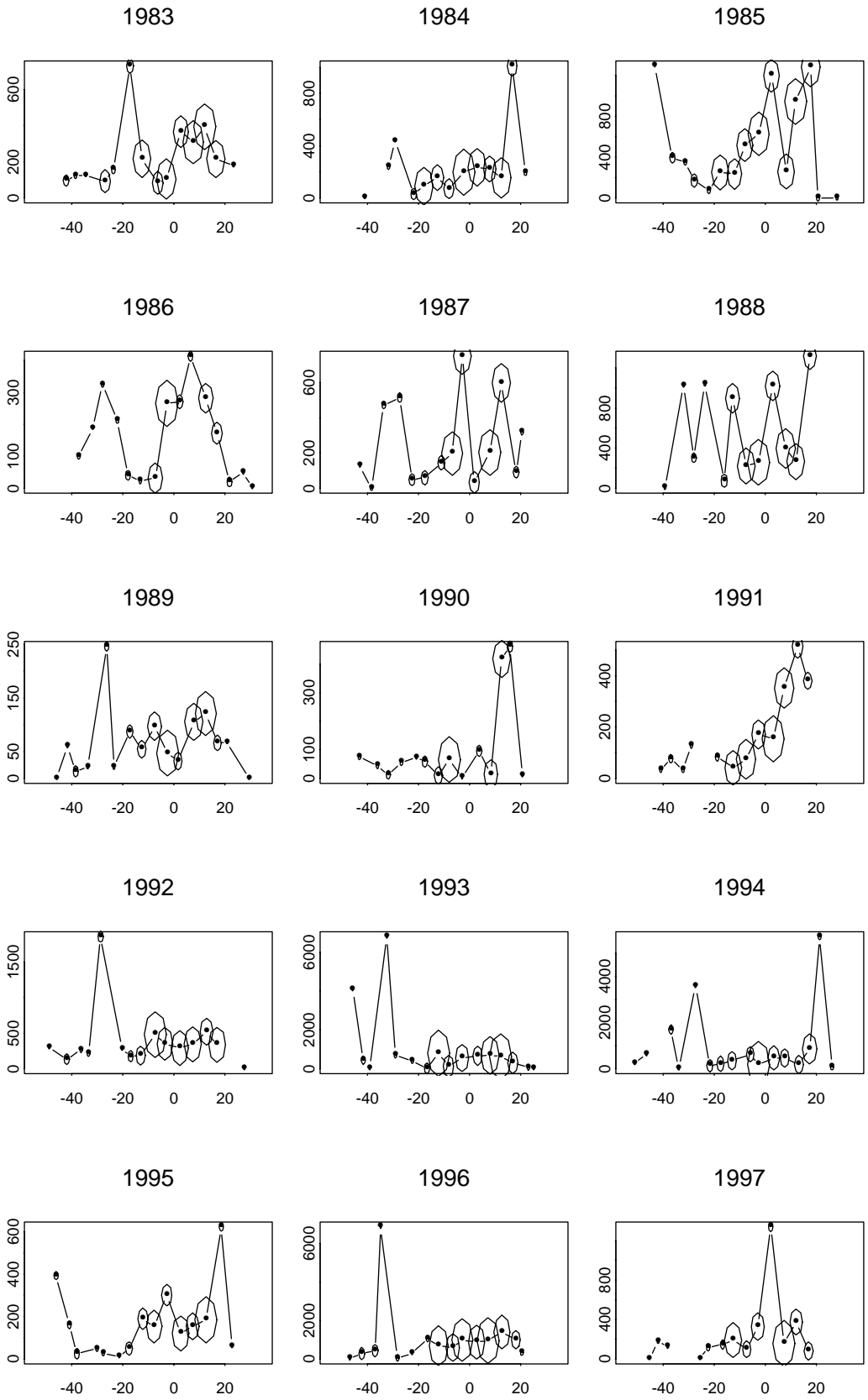


Fig. 5: Experimental regression of catches on sun elevation through years in quarter 1, in the example of haddock 2.

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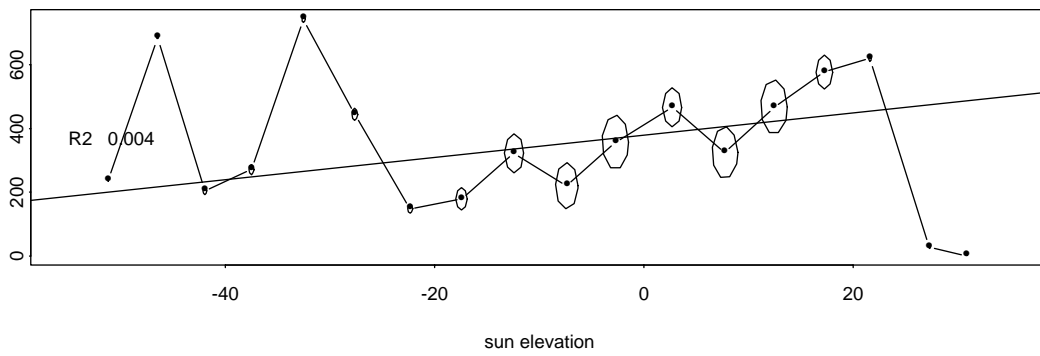
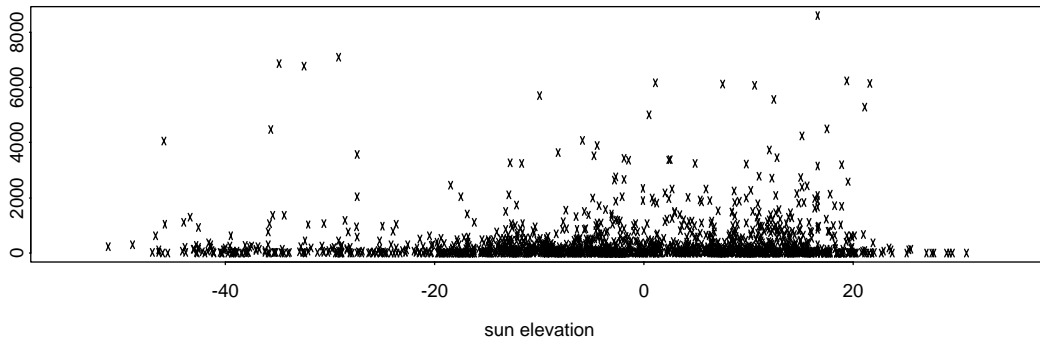
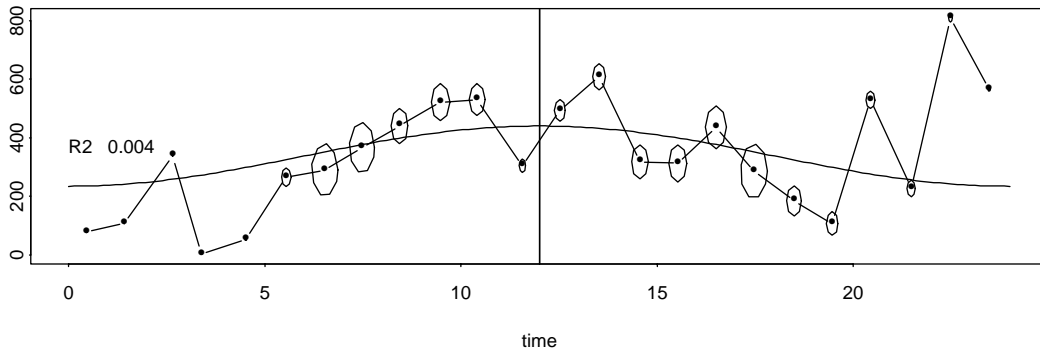
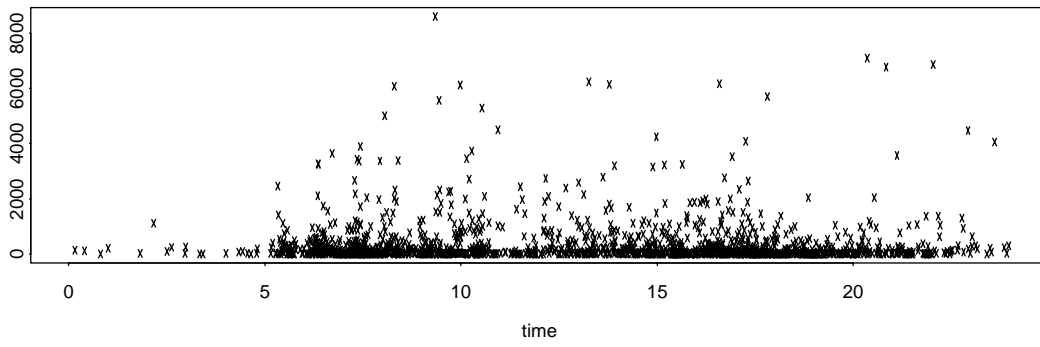


Fig. 6: Catches vs. time of day and sun elevation for all years together in quarter 1, in the example of haddock 2: plots of values and experimental regressions.

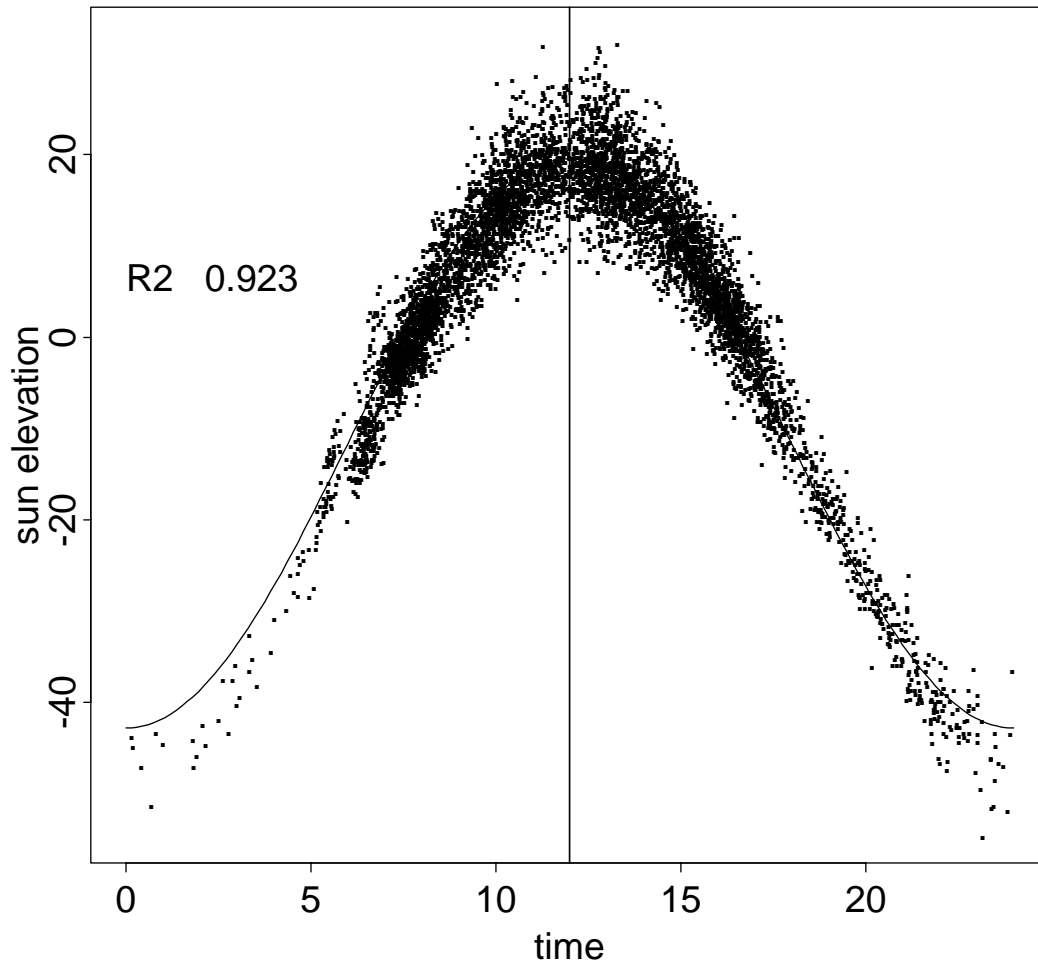


Fig. 7: Sun elevation on time of day for quarter 1 data (fitted by least squares with a cosine function maximal at noon: $-11.63+31.16 \cos(2\pi (t-12)/24)$)