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Stock assessment with a thermometer: correlations between sea surface temperature and landings of squid (*Loligo forbesi*) in Scotland

G. J. Pierce

Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen AB9 2TN, UK

Abstract Fishery data on landings and CPUE of squid *Loligo forbesi* in UK waters are analysed in conjunction with environmental data (sea surface temperature and salinity). For most fishery areas, satisfactory empirical relationships could be established, particularly for the northern North Sea, where Scottish squid landings in the peak months of the autumn coastal fishery could be forecast from mean February sea surface temperature in the central North Sea and mean May sea surface temperature in the northern North Sea. Landings and CPUE for squid in both Scottish and English autumn coastal fisheries were generally positively correlated with both mean sea surface temperature and mean salinity in various months during the same year, while negative correlations with hydrographic variables were seen for the summer squid fishery at Rockall. In some of the less important fishery areas, prediction was improved by incorporating survey abundance estimates. While direct and indirect mechanisms relating squid abundance to temperature are plausible, the most likely explanation lies in interannual variation in the strength of the Gulf Stream.

Introduction

Fluctuations in the abundance of a fished stock may arise from a variety of causes, both natural and man-made, including fishing, species-specific life-history traits, predation and climatic changes. Cephalopod stocks are thought to be particularly susceptible to environmental conditions (Caddy, 1983). This is partly because of the short life-cycle: e.g. many squids live for approximately one year and there is little overlap between successive generations. Consequently the population is not buffered against failure of recruitment. Also, growth patterns are highly labile: quite small changes in water temperature could result in large changes in growth patterns (Forsythe, 1993). Links have been established between environmental parameters and abundance for ommastrephid squids. Thus, Coelho & Rosenberg (1984) used multiple regressions and path analysis to show that water temperature could be a useful predictor of abundance in *Illex illecebrosus*. Rasero (1994) showed that survey abundance of *Todaropsis eblanae* was closely related to an "upwelling index" in Spanish coastal waters.

In Scottish waters, the veined squid *Loligo forbesi* is the only cephalopod of significant importance to fisheries. This species has an annual life cycle and is caught primarily as a by-catch of demersal trawl and seine net fisheries. Landings from coastal waters are consistently highest in October-December as the peak of the breeding season approaches and, in some years, there are also large amounts of squid caught in the Rockall area during June-August. There is considerable interannual variation in landings

(Pierce *et al.*, 1994a,b). This species is not assessed or managed and previous attempts to model the population dynamics have been restricted to describing intra-annual variations in abundance (Pierce & Guerra, 1994; Pierce & Santos, In Press).

Empirical, heuristic, models relating environmental parameters such as temperature and salinity to predict fishery abundance have been successfully applied to molluscs (Fogarty, 1989). The present paper represents a first attempt to investigate the role of environmental conditions in determining the abundance of a loliginid squid, *Loligo forbesi*, using environmental data along with fishery and survey data on squid abundance. The main approach used here is correlation and multiple regression analysis. Correlations do not, of course, indicate the existence of a causal relationship but the resulting simple empirical models may be used to generate testable hypotheses and, potentially, for forecasting stock abundance.

Materials and Methods

Data on landings of squid by UK-registered vessels in Scotland and associated fishing effort (hours fishing) were obtained from the FRS database at the Marine Laboratory Aberdeen (SOAFD). The data were for the period 1980-1994 and are classified by type of fishing gear, month, and ICES statistical rectangle. Monthly sums for all gears combined were derived for the main ICES fishery subdivisions in which squid are caught (IVa, IVb, VIa, VIb) and overall CPUE was calculated by dividing landings by hours fishing. Equivalent data for England and Wales were obtained from Lowestoft Fisheries Laboratory (MAFF). Landings or CPUE of squid are henceforth referred to as "fishery abundance": in the UK fishery they are thought to be reasonable indicators of abundance, particularly in Scotland where there is very little directed squid fishing (Pierce *et al.*, 1994a). Research cruise survey data supplied by SOAFD were used to produce survey abundance indices for the same period (see Pierce *et al.*, 1994c).

Hydrographical data (mean sea surface temperature and salinity) for the same period and geographical area were provided by ICES Oceanographic Data Centre, extracted to provide the same temporal and spatial resolution. Mean values (the mean of the mean values for relevant statistical rectangles) were calculated for each fishery subdivision.

The relationship between fishery abundance of squid and environmental parameters was explored using non-parametric correlation analysis and stepwise multiple regression analysis (BMDP Statistical Software). Only those variables with no missing data over 15 years were entered into the stepwise multiple regression analyses. These were: all landings, effort and CPUE variables (all gears combined), surface temperatures in areas IVa (February, April, May) and IVb (January to June, August to November), salinities in areas IVa (February, April, May and November) and IVb (January to June, August to November), survey abundance indices for North Sea surveys in February and August (areas IVa and IVb).

In all regressions, the dependent variable was a fishery abundance variable. Stepwise regression analyses were carried out with two sets of independent variables: (a) environmental parameters only, and (b) with environmental and survey index variables plus, when the dependent variable was a landings variable, fishing effort. The regressions were also run including the previous year's fishery abundance as independent variables but these variables never entered the regressions.

The stepwise multiple regression analysis program in many cases continued to enter variables until no residual variance remained. However, in these instances, a high proportion of variance was usually explained by the first 2 variables entered and regressions were therefore re-calculated using the first two predictor variables. Correlations are reported for the three independent variables, other than the predictors, which were most highly (positively or negatively) correlated with the dependent variable (including those excluded from the regressions *a priori* due to missing data).

Results

Fishery abundance of *Loligo* in Scotland from the autumn (October-December) fishery in the three main coastal fishery areas (IVa, IVb, VIa) was consistently well predicted from sea surface temperature in the first half of the same year (Table 1). Most of the predictor variables selected by the stepwise regression were individually significantly positively correlated with fishery abundance. [This is not necessarily the case since it is significant *partial* correlations that are required for entry into the stepwise regression.] Additional temperature and salinity variables were also significantly positively correlated with fishery abundance, including a number not entered into the regression analysis due to gaps in the data. Data for the Northern North Sea (area IVa) are illustrated in Figure 1.

Fishery abundance in the summer Rockall fishery was less predictable, but was negatively correlated with salinity in November of the same year. Most significant correlations of fishery abundance at Rockall with other environmental variables were negative (Table 1).

In the Scottish data, only for area IVb (central North Sea), which is of relatively minor importance in terms of mean annual landings (Table 1), was prediction of abundance improved by incorporating survey data, in this case a North Sea survey index from August (Table 2).

Fishery abundance of squid in the English and Welsh coastal fishery in the autumn was reasonably well predicted, for many fishery areas, from pairs of temperature and salinity variables (Table 1). Incorporation of survey indices improved prediction in some fishing areas (Table 2). Generally speaking, fishery abundance of squid was positively correlated with both temperature and salinity variables, although the opposite was the case for the summer Rockall fishery (Table 1).

Discussion

The positive correlations between autumn fishery abundance of squid and spring sea surface temperatures (among others) do not of course prove that squid abundance is directly controlled by sea surface temperature. One statistical problem which is difficult to take into account over such a relatively short time-series of data is the possibility of temporal autocorrelation between values of the same parameter in successive years.

Nevertheless, there are good arguments for temperature strongly affecting the biomass of *Loligo forbesi*: the fished stock consists almost entirely of recruits of the year (Pierce *et al.*, 1994b), and growth rates in the early life-stages of squids are very sensitive to temperature (Forsythe, 1993). Sea surface temperature would be expected to directly affect the planktonic juvenile stages rather than the demersal adults, but could also influence adults indirectly through effects on the abundance of food organisms. The CPR Survey Team (1992) showed that zooplankton abundance in the North Sea follows a similar trend to North Atlantic sea-surface temperature (1948-89)

Fishery abundance of squid from both English and Scottish autumn coastal fisheries was generally positively correlated with sea surface salinity variables as well as with temperature. Both sea surface temperature and salinity around the UK coast are higher in years when there is a stronger inflow of Atlantic waters carried by the Gulf Stream, and this inflow may result in passive movement of squid into coastal waters, particularly the northern North Sea. It has been speculated (P.R. Boyle, pers. comm.) that *Loligo forbesi* which breed in Scottish waters do not contribute to recruitment the following year, and that the Scottish population is maintained entirely by such immigration. The present analysis suggests that fishery abundance of *Loligo* in the summer fishery at Rockall tends to be negatively related to those environmental factors with which abundance in the autumn coastal fishery is positively correlated, indicating that, at least to some extent, abundance in the coastal fishery may be a function of distribution rather than overall abundance *per se*.

Stock size of long-lived finfish would be expected to be buffered against the effects of climatic variation, although Rothschild (1992) demonstrates that this is not necessarily the case, and climatic effects on recruitment and growth of fish in North Sea and adjacent waters have been documented for a number of species. In an extensive analysis of climatic variables in the North Sea, Svendson & Magnusson (1992) showed that over 70% of interannual variation in recruitment success of whiting (*Merlangius merlangus*) could be explained by an empirical model based on subsurface water heat content (high after mild winters or strong inflows of Atlantic water) and wind conditions in the second quarter of the year. Bailey & Steele (1991) showed that herring recruitment in the North Sea is dependent on oceanic inflow. Skjoldal *et al.* (1992) showed that annual mean increases in length and weight of two-year old capelin in the Barents Sea (1977-91) closely followed trends in sea temperature and salinity, apparently due to consequent changes in zooplankton abundance. Climatic effects can be seen across a range of species: the CPR Survey Team (1992) demonstrated that trends in abundance or reproductive success across four trophic levels in the North Sea, from phytoplankton upwards, broadly follow changes in North Atlantic sea surface temperature

While it may be interesting to speculate on the mechanism by which sea surface temperature and squid fisheries are related, this is arguably irrelevant for stock assessment. The results of the present analysis are encouraging, in that they suggest that methods requiring little data, based on empirical relationships between climatic variables and indices of the fishery abundance of squid, can produce satisfactory predictions of abundance. Making use of research cruise survey indices of abundance improved predictions only for a minority of fishery areas. The next steps will be to refine the model, seeking further climatic and hydrographic predictors, and to test it. Retrospective tests using pre-1980 data are one possibility but it is also intended to use the model to forecast landings in 1995 onwards.

This kind of exercise depends upon the availability of data from long term temperature and salinity monitoring. However, in the North Sea and English Channel, many series of long standing were discontinued during the 1980s (Ellett & Blindheim, 1992). It is to be hoped that satellite imagery can fill the gaps. In the future, the demise of many conventional finfish stocks may signal increased dependence of fisheries on short-lived species such as squid and, consequently, a shift away from conventional stock assessment methodologies towards empirical models.

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Table 1. Multiple Regression and Correlation Analyses of Squid Landings and CPUE. The best two environmental predictors from each stepwise regression analysis were used to generate new regressions. The table indicates the variables, the regression coefficents, F values, and the overall multiple correlation coefficients. Landings (tonnes) and CPUE (tonnes/1000 hrs) refer to the autumn fishery, except for area VIb where summer values are used.Temperatures are in °C and salinity in ‰. Also listed are Spearman's correlations between the dependent variable and (a) the predictors and (b) other related variables (see text). Mean landings for the relevant period and area are also indicated.

Dependent variable	*Intercept*	*Predictor 1*	*Predictor 2*	*Multiple R^2*	*Other highest significant correlations*				
					Data	*Area*	*Month*	r_s	*N*
Scottish landings IVa		Temp IVb Feb	Temp IVa May	0.907	Temp	IVa	Feb	0.711	15
(mean=173 tonnes)	-1037.8	108.11 (F=40.7)	74.41 (F=23.2)		Temp	IVa	Oct	0.692	13
		r_s=0.693	r_s=0.850		Temp	VIa	Jun	0.786	8
Scottish CPUE IVa		Temp IVb Feb	Temp IVa May	0.842	Temp	IVa	Feb	0.689	15
	-4.70	0.46 (F=19.6)	0.37 (F=14.8)		Temp	IVa	Oct	0.665	13
		r_s=0.739	r_s=0.761		Temp	VIa	Jun	0.762	8
Scottish landings IVb		Temp IVa Feb	Temp IVb May	0.693	Temp	IVa	May	0.775	15
(mean=24 tonnes)	-226.26	22.05 (F=9.9)	10.77 (F=4.5)		Temp	VIb	Apr	0.755	11
		r_s=0.718	r_s=0.539		Sal	VIa	Oct	0.714	13
Scottish CPUE IVb		Temp IV a Feb	Temp IVb May	0.704	Temp	IVa	May	0.743	15
	-2.23	0.22 (F=10.6)	0.10 (F=4.6)		Temp	VIb	Apr	0.809	11
		r_s=0.729	r_s=0.504		Sal	VIa	Oct	0.762	8
Scottish landings VIa		Temp IVa Feb	-	0.601	Temp	IVa	May	0.829	15
(mean=103 tonnes)	-487.30	85.77 (F=19.4)			Temp	VIb	Apr	0.736	11
		r_s=0.793			Sal	IVa	Sep	0.731	13
Scottish CPUE VIa		Temp IVa May	Temp IVb Feb	0.684	Temp	IVa	Feb	0.761	15
	-1.63	0.14 (F=7.0)	0.16 (F=6.9)		Temp	IVb	Jun	0.675	15
		r_s=0.768	r_s=0.621		Temp	VIa	Jun	0.667	8
Scottish landings VIb		Sal IVa Nov	Sal IVb Apr	0.476	Temp	IVa	Sep	-0.625	13
(mean=112 tonnes)	4578.20	-177.89 (F=9.9)	48.95 (F=4.3)		Temp	IVb	Dec	0.635	13
		r_s=-0.072	r_s=0.018		Temp	VIa	May	-0.738	10
Scottish CPUE VIb		Sal IVa Nov	-	0.276	Temp	VIa	May	-0.622	10
	511.20	-14.70 (F=5.0)			Sal	VIa	May	-0.699	10
		r_s=-0.108			Sal	VIa	Nov	-0.661	11
Scottish landings		Temp IVb Feb	Temp IVa May	0.914	Temp	IVa	Feb	0.750	15
(sum, excluding VIb)	-1675.53	176.94 (F=44.2)	121.37 (F=25.1)		Temp	IVb	Jun	0.711	15
(mean=300 tonnes)		r_s=0.686	r_s=0.829		Temp	VIa	Jun	0.762	13
Scottish CPUE		Temp IVb Feb	Temp IVa May	0.893	Temp	IVa	Feb	0.704	15
(overall, excluding VIb)	-0.0276	0.028 (F=31.6)	0.021 (F=22.3)		Temp	IVb	Jun	0.682	15
		r_s=0.746	r_s=0.768		Temp	VIa	Jun	0.738	8
English landings IVa		Sal IVb Jan	Sal IVb May	0.602	Temp	IVb	May	0.582	15
(mean=0.6 tonnes)	-9.58	0.52 (F=12.9)	-0.22 (F=9.3)		Sal	IVa	Jun	0.550	13
		r_s=0.593	r_s=-0.172		Temp	IVa	Sep	0.544	13
English CPUE IVa		Temp IVb May	Sal IVb Jan	0.772	Temp	IVa	Feb	0.632	15
	-4.61	0.17 (F=28.3)	0.098 (F=6.9)		Temp	VIb	Apr	0.655	11
		r_s=0.714	r_s=0.589		Sal	VIa	Jun	0.667	8
English landings IVb		Temp IVa Feb	Temp IVb Oct	0.738	Temp	VIa	Apr	0.653	14
(mean=16.6 tonnes)	-286.68	22.82 (F=26.4)	11.93 (F=7.4)		Sal	VIa	Oct	0.762	8
		r_s=0.625	r_s=0.289		Sal	IVb	Jul	0.714	15
English CPUE IVb		Temp IVa Feb	Temp IVb Oct	0.744	Sal	IVb	Jan	0.725	15
	-2.40	0.20 (F=28.3)	0.095 (F=6.7)		Sal	IVb	Jul	0.771	14
		r_s=0.546	r_s=0.357		Sal	VIa	Oct	0.786	8
English landings IVc		Sal IVb Oct	Sal IVa Feb	0.672	Temp	VIa	Jun	0.691	8
(mean=1.0 tonnes)	297.04	0.54 (F=15.9)	-8.96 (F=12.5)		Temp	VIb	Apr	0.727	14
		r_s=0.857	r_s=0.061		Sal	IVb	Apr	0.732	15
English CPUE IVc		Sal IVa Nov	Sal IVb Oct	0.607	Sal	IVb	Apr	0.804	15
	-1.77	0.037 (F=9.6)	0.017 (F=8.0)		Sal	IVb	Jul	0.824	14
		r_s=0.179	r_s=0.704		Sal	VIa	Sep	0.789	14
English landings VIa		Temp IVb Feb	-	0.323	Temp	IVa	Jan	0.643	12
(mean=1.8 tonnes)	-7.99	1.82 (F=6.2)			Temp	IVa	Feb	0.568	15
		r_s=0.614			Sal	IVb	Jan	0.525	15
English CPUE VIa		Temp IVa Feb	-	0.0.397	Temp	VIa	Jun	0.738	8
	-5.66	0.96 (F=8.6)			Temp	IVb	Feb	0.607	15
		r_s=0.700			Temp	VIa	May	-0.596	10
English landings VIb		Temp IVb Sep	-	0.416	Temp	VIa	May	-0.675	10
(mean=13.8 tonnes)	301.99	-19.45 (F=9.3)			Sal	IVa	Jul	0.636	12
		r_s=-0.550			Sal	VIa	May	-0.612	10
English CPUE VIb		Temp IVb Sep	-	0.335	Temp	VIa	May	-0.693	10
	124.71	-7.92 (F=6.5)			Sal	IVa	Jul	0.622	12
		r_s=-0.431			Sal	VIa	May	-0.612	10
English landings VIIa		Sal IVb Oct	Temp IVa May	0.691	Temp	IVa	Feb	0.593	15
(mean=32.7 tonnes)	-297.36	7.66 (F=13.3)	9.50 (F=7.8)		Temp	VIa	Jun	0.619	8
		r_s=0.810	r_s=0.571		Temp	VIb	Apr	0.591	11
English CPUE VIIa		Sal IVb Oct	Temp IVb Nov	0.716	Temp	VIa	Jun	0.714	8
	-10.07	0.25 (F=23.9)	0.26 (F=8.8)		Sal	IVa	Jul	-0.629	12
		r_s=0.893	r_s=0.304		Sal	IVa	Dec	0.636	11

Dependent variable	*Intercept*	*Predictor 1*	*Predictor 2*	*Multiple R^2*	*Other highest significant correlations*				
					Data	*Area*	*Month*	r_s	*N*
English landings VIId (mean=11.5 tonnes)	-60.61	Sal IVb Apr 5.18 (F=20.9) r_s=0.818	Temp IVb Oct -7.60 (F=6.3) r_s=0.050	0.656	Temp Temp Sal	VIa VIb IVb	Sep Apr Aug	-0.855 0.718 0.689	14 11 15
English CPUE VIId	-16.09	Sal IVb Apr 0.21 (F=15.0) r_s=0.896	Sal IVb Jan 0.30 (F=5.7) r_s=0.661	0.678	Temp Sal Sal	VIb IVb VIb	Apr Jul Sep	0.718 0.745 0.732	11 14 14
English landings VIIe (mean=190 tonnes)	-959.78	Sal IVb Apr 30.02 (F=19.6) r_s=0.807	Temp IVb Feb 35.83 (F=5.8) r_s=0.464	0.728	Temp Temp Temp	IVa IVb VIb	Jan Dec Apr	0.860 0.731 0.809	12 13 11
English CPUE VIIe	-28.69	Temp IVb Sept 1.14 (F=19.0) r_s=0.714	Sal IVb Apr 0.45 (F=12.8) r_s=0.650	0.728	Sal Sal Sal	IVa IVb IVb	Dec Jan Jul	0.746 0.739 0.780	11 15 14
English landings VIIf (mean=14 tonnes)	-163.99	Sal IVb Apr 1.79 (F=11.4) r_s=0.757	Sal IVb Sep 3.62 (F=4.9) r_s=0.446	0.610	Temp Temp Sal	IVa VIb VIa	Nov Apr Oct	0.732 0.709 0.881	14 11 8
English CPUE VIIf	-4.72	Temp IVb Sep 0.58 (F=11.9) r_s=0.600	Temp IVb Jan -0.49 (F=8.5) r_s=-0.189	0.605	Sal Sal Sal	IVb VIa VIa	Jan Sep Oct	0.668 0.688 0.810	15 14 8
English landings VIIg-k (mean=16 tonnes)	-25.55	Temp IVb Feb 7.84 (F=9.1) r_s=0.604		0.412	Temp Temp Sal	IVa IVb IVb	Jan Apr Jun	0.601 0.589 0.593	12 15 15
English CPUE VIIg-k	-0.91	Temp IVb Apr 0.29 (F=4.4) r_s=0.364		0.251	Temp Temp Sal	IVa IVb VIa	Jun Sep Mar	0.626 0.586 0.650	13 15 9
English landings (sum, excluding VIb) (mean=285 tonnes)	-1512.48	Sal IVb Apr 44.61 (F=23.9) r_s=0.846	Temp IVb Feb 69.75 (F=6.4) r_s=0.489	0.795	Temp Temp Sal	IVa VIb IVa	Jan Apr Dec	0.790 0.809 0.718	12 11 11
English CPUE (overall, excluding VIb)	-16.71	Sal IVb Jan 0.37 (F=27.1) r_s=0.836	Sal IVb Apr 0.15 (F=25.2) r_s=0.707	0.844	Sal Sal Sal	IVa IVb VIa	Dec Jul Sep	0.764 0.741 0.873	11 14 14

Table 2. Multiple Regressions of Squid Landings and CPUE for which survey or effort variables were among the best two predictors. As before, the best two predictors from each stepwise regression analysis were used to generate new regressions. The table indicates the variables, the regression coefficents, F values, the overall multiple correlation coefficients, and Spearman's rank correlations between the dependent variable and the predictors. Landings are in tonnes, effort in hours, CPUE in tonnes/1000 hours, temperature in °C and salinity in ‰. For survey indices, the mantle length class (cm) is indicated.

Dependent variable	*Intercept*	*Predictor 1*	*Predictor 2*	*Multiple R^2*
Scottish landings IVb	-117.38	Index Aug (10-15) 30.47 (F=16.6) r_s=0.420	Temp IVa Feb 19.38 (F=13.6) r_s=0.718	0.823
Scottish CPUE IVb	-1.19	Index Aug (10-15) 0.29 (F=15.7) r_s=0.413	Temp IVa Feb 0.20 (F=14.4) r_s=0.729	0.823
English landings IVa	56.64	Index (all) Aug 0.24 (F=33.4) r_s=0.749	Sal IVb Feb -1.65 (F=12.9) r_s=-0.107	0.754
English landings VIa	-11.10	Temp IVb Feb 2.54 (F=12.7) r_s=0.614	Index (10-15) Aug -2.81 (F=5.1) r_s=0.157	0.525
English CPUE VIa	-7.61	Temp IVa Feb 1.29 (F=15.3) r_s=0.700	Index (10-15) Aug -1.00 (F=4.6) r_s=0.204	0.563
English landings VIIg-k	9.00	Index (<10) Feb 0.26 (F=28.7) r_s=0.305	Fishing Effort 0.0022 (F=9.5) r_s=0.489	0.754
English CPUE VIIg-k	-2.97	Index (<10) Feb 0.012 (F=17.8) r_s=0.489	Temp IVb Sep 0.25 (F=6.4) r_s=0.586	0.671

Figure 1. Interannual variation in squid abundance and environmental parameters:

(a) (i) Landings of *Loligo* from ICES fishery subdivision IVa (northern North Sea) into Scotland, October-December
(ii) Fishing effort in area IVa by vessels landing in Scotland, October-December
(iii) Overall CPUE for *Loligo* in area IVa by vessels landing in Scotland, October-December.

(b) (i) Mean sea surface temperature in area IVa in May
(ii) Mean sea surface temperature in area IVb in February

(c) (i) Landings of *Loligo* from ICES fishery subdivision IVa (northern North Sea) into Scotland, October-December
(ii) Predicted landings, based on multiple regression on the two temperature variables