Daily catches of *Loligo vulgaris* and the fishing effort of commercial beach-seiners operating along the coasts of the Thracian Sea were recorded between October 1994 and May 1995. Taking into account the spatial distribution of the ports, the squid fishing grounds and the daily activity of the beach-seiners, five coastal zones were determined for the monitoring of fishery data. Multivariate analysis failed to show significant differences between the monthly catch rate (cpue) in the zones. However, *Loligo vulgaris* cpue was clearly seasonal, with a distinct peak in November and an evident decline from winter to spring. Temperature, rainfall and local wind records were used in making a preliminary investigation into meteorological factors that may affect beach-seine catches of squid. Multiple linear regression analysis revealed that temperature is a highly significant explanatory variable for cpue variation, whereas the intensity of the wind plays an important role, but mostly during winter. Rainfall was significantly related to variation in cpue in one zone. Cpue was generally negatively correlated with air temperature and rainfall. Most significant correlations of cpue with wind were also negative.

*Loligo vulgaris* is a nektobenthic species found over the continental shelf, generally up to a depth of 200 m (Boyle and Boletzky 1996). It is one of the most common squid species along the coasts of the North-East Atlantic and the Mediterranean Sea, where it is known as the European squid. In the Mediterranean, and especially in Spain, Italy and Greece, *Loligo vulgaris* is part of the traditional diet and plays an important role in local fish markets. Nevertheless, there is no specialized commercial fishery for it, and it is taken mainly as a bycatch of the multispecies trawl fishery. However, some directed handline jig-fishing, particularly artisanal fishing in coastal waters, is undertaken by a small number of fishermen and/or as a sport (Simon et al. 1996, Lefkaditou et al. in press). In Greek waters, the average annual catch of European squid over the past decade was some 1 080 tons, 38% of which was taken by bottom trawl, 30% by beach-seine, 9% by purse-seine and 23% by other gear in small-scale fisheries. In the Thracian Sea, European squid may be considered as a target beach-seine species, because it constitutes 10% of the total beach-seine catches and 27.5% of the total income of the fishers (Lefkaditou et al. in press). Inspection of fishery statistics reveals considerable seasonal and interannual variation in European squid catches in the Thracian Sea. Annual catches of other coastal loliginids, such as *Loligo forbesi* in Scottish waters, *L. opalescens* off California and *L. pealei* in the NW Atlantic, also vary extensively and unpredictably (Boyle 1990). These fluctuations arise mainly from features of the life cycle and as a response to environmental stimuli (Caddy 1983, Boyle and Boletzky 1996); indeed, they may be a function of distribution rather than an index of overall abundance of the stocks (Pierce 1995). Links have been established between annual fluctuations in environmental parameters and landings of loliginid squids by Roberts and Sauer (1993) and Pierce (1995). Further, short-term changes in sea surface temperature and wind direction have been demonstrated to influence the behaviour and distribution of the adults of a closely related loliginid, *Loligo vulgaris reynaudi*, in their inshore spawning grounds (Sauer et al. 1991). Their availability to the inshore jig catches varies as a consequence.

In the Mediterranean Sea, the annual migration pattern of *Loligo vulgaris* was studied by Worms (1983), who showed spawning-cycle-related seasonal short-range movements, influenced evidently by oceanographic conditions. The available information about sea surface temperature and salinity inhabited by *L. vulgaris* is unfortunately limited. It seems that *Loligo vulgaris* is found in shallow water of surface temperature 11.3–22.7°C and salinity >30×10⁻³ (Tinbergen and Verwey 1945, Baddy 1988). Temperature and salinity ranges under experimental conditions have been demonstrated as 13.3–26.0°C and 34–37×10⁻³ respectively (Boletzky 1979, Turk et al. 1986).
In certain cases, oceanographic conditions seem to be closely related to meteorological conditions, although linkage of a realistic oceanographic component to a general circulation model of the atmosphere has yet to be accomplished (Glantz and Feingold 1992). Southward et al. (1988) noted that surface water temperature in coastal waters is reasonably correlated with air temperature. Astraldi et al. (1995) consider that air temperature could serve as a guide for investigating trends in sea surface temperature in the Ligurian Sea. It is worth noting that, in the northern Aegean Sea, sea surface temperature is significantly correlated with air temperature and sea level pressure (Stergiou and Christou 1996). Therefore, meteorological changes may indirectly influence the distribution and availability of species inhabiting shallow coastal water.

This study represents a preliminary investigation of the effect of meteorological factors on the availability of Loligo vulgaris on the inshore fishing grounds of the Thracian Sea, during eight months of fishing. In particular, the likely relationship between air temperature, wind, rainfall and catch rate of Loligo vulgaris caught by beach-seine is examined through multiple regression analysis.

MATERIAL AND METHODS

Environmental and fisheries background

The Thracian Sea has an area of approximately 9480 km² and typically variable geomorphology and hydrology; it is the largest trawling area in Greek waters (Fig. 1). The continental shelf (<200 m) extends to a distance of between 5 and 27 miles from the coast. Most of the sea bed is coarse or muddy sand, the latter particularly near the run-offs of the rivers and the coasts of the city of Kavala. There are seagrass meadows almost all around the coast, but they are particularly extensive around the islands of Thasos and Samothraki. Extended detritic communities are found three miles from the east coast of Thasos, at depths of 55–70 m, and north-west of Thasos.

The most distinct hydrological feature in the Thracian Sea is the intrusion of water of Black Sea origin, low in salinity, which occupies the whole surface layer and contributes to the maintenance of low salinity (33–36×10−3) from the surface down to depths of 50–60 m. Deeper than that, the salinity generally reaches normal values for the Aegean Sea (about 38.8×10−3). The inflow of Black Sea water is stronger during late spring and summer, corresponding to an increase in river run-off and precipitation over the Black Sea. West of Thasos, salty Aegean water enters from the south-west to form a haloclinic front and a cyclonic circulation pattern south of the island. There, the salinity is relatively high (35–37×10−3). Outflow from the three main rivers (Strymonas, Nestos and Evros) does not disturb the overall picture, although some tongues of low salinity are observed over the delta run-offs (Papaconstantinou et al. 1994). In the northern Aegean Sea, the NE part of which is called the Thracian Sea, sea surface temperature is significantly correlated with air temperature and reaches a maximum (22–25°C) in August and a minimum (14–16°C) in
Table I: Multiple regression and correlation coefficients between the log-transformed 
\( \text{cpue} \) of \textit{Loligo vulgaris} and three meteorological variables: air temperature
\( T \) (in °C), wind speed \( W \) (NE-SW component, in knots) and rainfall \( R \) (in mm). \text{cpue} refers to the beach-seine fishery in the Thracian Sea during the 
fishing period October 1994 – May 1995. The analyses were performed on the combined data from seven boats and for five of the boats separately, 
for the whole fishing period as well as for shorter periods, as shown below

<table>
<thead>
<tr>
<th>Period over which the data were analysed</th>
<th>Boats</th>
<th>Intercept and regression coefficients of the model ( \log (\text{cpue} + 1) = a + bT + cW + dR )</th>
<th>Multiple ( R^2 ) (%)</th>
<th>( F )-ratio and Spearman’s rank correlation coefficients of Temperature Wind Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 1994 – May 1995</td>
<td>All</td>
<td>3.3403</td>
<td>-0.0952</td>
<td>0.0426</td>
</tr>
<tr>
<td>September – November 1994</td>
<td>All</td>
<td>5.6767</td>
<td>-0.1976</td>
<td>-0.1522</td>
</tr>
<tr>
<td>December 1994 – January 1995</td>
<td>All</td>
<td>2.9056</td>
<td>-0.1185</td>
<td>26.17</td>
</tr>
<tr>
<td>February – March 1995</td>
<td>All</td>
<td>2.2074</td>
<td>-0.0797</td>
<td>-0.2818</td>
</tr>
<tr>
<td>April – May 1995</td>
<td>All</td>
<td>3.0642</td>
<td>-0.3643</td>
<td>25.04</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 1</td>
<td>1.6692</td>
<td>-0.0603</td>
<td>-0.0076</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 2</td>
<td>2.8321</td>
<td>-0.1045</td>
<td>-0.0806</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 3</td>
<td>1.4895</td>
<td>-0.0644</td>
<td>38.89</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 4</td>
<td>1.2601</td>
<td>-0.0392</td>
<td>14.72</td>
</tr>
<tr>
<td>December 1994 – March 1995</td>
<td>Boat 5</td>
<td>2.2561</td>
<td>-0.0890</td>
<td>-0.0597</td>
</tr>
<tr>
<td>April – May 1995</td>
<td>Boat 6</td>
<td>1.4524</td>
<td>-0.0891</td>
<td>25.24</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 7</td>
<td>1.7515</td>
<td>-0.0406</td>
<td>-0.0331</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 8</td>
<td>2.5688</td>
<td>-0.0693</td>
<td>8.26</td>
</tr>
<tr>
<td>October – November 1994</td>
<td>Boat 9</td>
<td>1.7401</td>
<td>-0.0638</td>
<td>21.87</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 10</td>
<td>1.7372</td>
<td>-0.0660</td>
<td>27.19</td>
</tr>
<tr>
<td>October – November 1994</td>
<td>Boat 11</td>
<td>2.5882</td>
<td>-0.1155</td>
<td>58.40</td>
</tr>
<tr>
<td>April – May 1995</td>
<td>Boat 12</td>
<td>2.0644</td>
<td>-0.0856</td>
<td>25.94</td>
</tr>
<tr>
<td>October 1994 – May 1995</td>
<td>Boat 13</td>
<td>1.4050</td>
<td>-0.0231</td>
<td>-0.2389</td>
</tr>
<tr>
<td>October – November 1994</td>
<td>Boat 14</td>
<td>1.4603</td>
<td>-0.2728</td>
<td>45.02</td>
</tr>
<tr>
<td>February – March 1995</td>
<td>Boat 15</td>
<td>1.0078</td>
<td>-0.2103</td>
<td>27.90</td>
</tr>
<tr>
<td>April – May 1995</td>
<td>Boat 16</td>
<td>1.3210</td>
<td>-0.0382</td>
<td>21.07</td>
</tr>
</tbody>
</table>
February (Stergiou et al. 1997).

The fishing activity of beach-seiners nowadays is concentrated in the western part of the Thracian Sea and particularly along the coasts indicated in Figure 1. The shores from Keramoti to Alexandroupoli, although sandy, are inappropriate for beach-seine operations because of their low inclination and shallow water, whereas on the north coast of Thasos, the extensive use of fyke-nets for octopuses has made fishing with beach-seine impossible for the past 10 years.

Beach-seines are rarely used in the Mediterranean, but are quite important in the Greek coastal fishery. The Greek beach-seine fishing fleet currently numbers some 640 vessels and employs about 2,000 persons. Despite its name, the gear is really a boat-seine and the net is hauled by a special winch. The boats are 7–14 m long. However, according to Greek legislation, the gear is operated very close to shore, the boats anchoring within 70 m of the coast. Beach-seine nets used in the study area are 200–250 m long and 35–50 m deep, so covering an area of 20,000–180,000 m² in a single haul. Stretched mesh sizes range from the legal minimum of 16 mm at the codend to 1,000 mm in the wings.

Although there is a closed season for beach-seining extending from 1 June to 30 September, the gear is considered harmful to mullet and sparids owing to the catch of juveniles inshore. That situation has prompted fisheries managers to propose outlawing use of the gear after 2002 (European Community Regulation No 1626/27-6-94/L.171/1).

**Data collection and analysis**

Total daily landings of beach-seiners, including squid, were recorded between October 1994 and May 1995. During this fishing period, only seven of the nine registered boats operated along the coast of the western Thracian Sea. Four of them landed their catches at Kavala and three at fishing shelters on Thasos (two at Kallirahi and one at Potamia; Fig. 1). Five coastal zones were demarcated for monitoring catch-and-effort data, taking into account the spatial distribution of the ports, the fishing grounds for squid and the daily activity of the beach-seiners.

At Kavala, data were collected at the auctions. This was carried out through personal observation for 138 days out of the total of 208 days devoted to fishing. The activity of the beach-seiners landing at Thasos was not monitored daily because of time and distance constraints, but in terms of weekly reports. Days of activity, number of hauls, fishing zone and catch data were listed through receipts of sale and interviews.
with the fishermen. As it was not possible to know the catch per haul, catch per boat-day was used as a unit of fishing effort.

The catch per unit effort (cpue) for each of the five fishing zones was analysed on a monthly basis. A daily average cpue was calculated from all seven vessels, and a Bray-Curtis (Bray and Curtis 1957) measure of similarity applied to detect differences in cpue and the catches of Loligo vulgaris between the different zones.

Local records of average daily air temperature (°C), daily rainfall (mm), hourly wind speed (knots) and wind direction were provided by the National Meteorological Service.

The relationship between the cpue of European squid and meteorological factors was explored using non-parametric correlation analysis and multiple regression analysis (STATGRAPHICS Plus 2.0 Software). The analyses were performed for the whole fishing period monitored and also for shorter periods (see Table I), following the trends in the Loligo vulgaris catch. Catch rates were examined for all vessels combined and separately for the five boats that had no missing data for the eight months of the study period.

For the statistical analyses, the hourly wind data were smoothed to 24-h values and orientated to a NE-SW axis direction. Cpue values were log-transformed and zero values included in the analyses. In all regression analyses, the dependent variable was cpue, and the meteorological factors (air temperature, wind, rainfall) were entered as independent variables.

The model used in the multiple regression analysis was as follows:

$$\log (cpue_i + 1) = a + bT_i + cW_i + dR_i$$

where Log is the natural logarithm, $T_i$ the air temperature (in °C), $W_i$ the wind speed in knots (NE-SW component), and $R_i$ the rainfall (in mm). At first, all three independent variables were entered in the multiple regression analysis, but when the $p$-value associated with the significance of a variable was >0.1, that variable was excluded from the model and regressions were re-calculated using the remaining variables. Correlations

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**Fig. 3:** Monthly variation in (a) daily catch of Loligo vulgaris and (b) beach-seine fishing activity during the fishing period October 1994 – May 1995 in the Thracian Sea
are reported for all three independent variables.

RESULTS

The fishing activity of beach-seiners by zone during the fishing period October 1994 – May 1995 is shown on Figure 2. The activity level of the vessels in each zone seems to be related primarily to the distance from the fishing harbours and only secondly to the relative abundance of the target species.

The lowest level of fishing activity was in Zone 1; there, only one vessel from Potamia was fishing despite there almost always being L. vulgaris in the daily catches. There was also a low level of fishing activity in Zone 2, because one of the two Kallirahi vessels was involved in a different type of fishing activity after January.

The fishing grounds of Zones 3, 4 and 5 were mainly exploited by the four vessels of Kavala. The highest level of fishing activity was in Zone 3, and the same zone realized the greatest number of fishing days with L. vulgaris in the catch. Zone 3 is close to lagoons and is inhabited by other commercially important species (e.g. Lithognathus mormyrus) targeted directly by the beach-seine fishery. In Zone 5 there was no fishing activity during January or February, probably because that area is quite far from shelter and is quite vulnerable to bad weather. However, in Zone 5, the frequency of L. vulgaris in the catches was the highest of all zones. Therefore, despite the relatively greater distance of Zone 5 from Kavala, the highest level of exploitation was there in November, the month of greatest abundance of L. vulgaris.

Peak beach-seine activity throughout the study area was in October-November and the lowest level of activity in February (Fig. 3b). In November L. vulgaris was found in all daily landings monitored. Lowest frequency of occurrence of the species was in October. Average monthly catch rates of Loligo vulgaris were clearly seasonal, peaking in November and declining from winter to spring. Daily catches also peaked in November (Fig. 3a).

Multivariate analysis failed to reveal significant differences between the monthly cpue in the five fishing zones. However, among monthly cpue values, those of January and February were separated at a 75% (Bray-Curtis) similarity level (Fig. 4).

Average daily values of temperature, wind speed and daily rainfall during the study period are plotted on Figure 5 together with squid cpue and fishing effort. It appears that cpue increases with decreasing temperature (down to 7°C) during the first two months of the study, that a further decline of temperature inverts this trend during December and January, but that temperature effects on cpue fluctuations are not obvious during the following months. Winds blowing from the north-east seem generally to result in decrease of air temperature. Strong south-west winds (>5 knots), supposedly correlated with coastal water turbidity, were recorded during spring only, when the low abundance of L. vulgaris did not permit detection of their effect on catches and catch rates.

The multiple linear regression analyses confirmed the highly significant relationship between cpue and temperature in almost all cases (Table I). Wind also played a significant role in the overall cpue, explaining a higher percentage of cpue variation in the two-month periods December/January (15.24%) and February/March (13.12%). Rainfall was significantly related to overall cpue only in late winter (F = 15.94). However, it appeared to play the most important role in the variation of the cpue of Boat 5 operating in Zone 1, where surface salinity is relatively lower (Papacosstantinou et al. 1994). The catch rate was generally negatively correlated with air temperature and rainfall, whereas most significant correlations of cpue with wind were also negative.

The linear models developed could not explain the variability in the overall cpue values. Although the $R^2$ value increased when the analysis was performed for October-November, it exceeded 50% only for the cpue of Boats 1 and 4.

DISCUSSION

Subtle changes in fundamental environmental vari-
Fig. 5: Average daily values of (a) rainfall, (b) wind speed (winds with a north-easterly component are given a positive wind speed, south-westerlies a negative one), (c) temperature, (d) European squid cpue (kg/boat-day), (e) number of active boats (fishing effort).
ables (temperature, salinity, winds, currents) can alter the abundance, distribution and availability of fish populations sharply (Glantz 1992). For squid, sea surface temperature may be considered as the key environmental variable affecting their availability either directly or indirectly (Pierce 1995, Boyle and Boletzky 1996).

Direct environmental effects on migration patterns, spawning intensity and on planktonic juvenile stages of squid have been documented. Migration of the maturing animals towards the coast, proposed by Worms (1983), is influenced by sea surface temperature and results in two peaks of spawning, following the two mating periods of January and April. Spawning intensity of *Loligo vulgaris reynaudii* has been related to sea surface temperature variability by Sauer et al. (1991). Further, a highly significant relationship between annual fluctuations in sea surface temperature in the North Sea and landings of *Loligo forbesi* in Scotland has been established by Pierce (1995). Temperature is considered crucial in egg survival of *L. v. reynaudii* (Augustyn 1989), and it is also thought to influence growth rates in the early life history of squid (Forsythe 1993). Finally, the indirect effects of temperature can be related to the abundance of food available to adult squid. For instance, zooplankton abundance in the North Sea follows a similar trend to North Atlantic sea surface temperature (Pierce 1995).

In the Thracian Sea, the availability of *Loligo vulgaris* on the inshore fishing grounds peaked in the second half of November 1994 and to a lesser extent in the second half of January 1995 (Fig. 5). In other years, catch statistics reveal a later period of good beach-seine and hand-jigging catches of squid between late March and May. The relatively cooler weather of spring 1995 may have postponed the migration inshore of *Loligo vulgaris*. Most (>80%) of the *Loligo vulgaris* caught by beach-seines from February to May in the Thracian Sea are fully mature or partially spent (EL, unpublished data), suggesting that the poor catches during spring may be due also to a high level of post-spawning mortality. The scarcity of *L. vulgaris* in October 1994, however, may well be due to the fact that the animals had not fully recruited to the beach-seine fishing grounds inshore, because in the same month, trawl catches of *Loligo vulgaris* peaked (Tsangridis et al. 1998). The documented seasonal bathymetric distribution by size in the western Mediterranean suggests that large (maturing or mature) squid move inshore in autumn and winter, probably to spawn (Sánchez and Guerra 1994).

The present results suggest a relationship between temperature and the availability of European squid on the inshore fishing grounds, although air temperature has been used rather than sea surface temperature. It is known, however, that there is a reasonable correlation between the two parameters in coastal waters (Southward et al. 1988, Astraldi et al. 1995).

Wind and rainfall were generally less significantly related to the availability of *Loligo vulgaris*, indicating that, at least in the Greek beach-seine fishery, the most appropriate meteorological variable is air temperature. The high significance of rainfall in the variation of cpue in Zone 1 is exceptional and probably related to the relatively lower surface salinity east of Thasos (Papconstantinou et al. 1994).

For now, however, it is still too early to take matters further and to suggest empirical relationships between indices of squid abundance and meteorological variables; the present data, although detailed, are after all restricted to a single year (and generation of *Loligo vulgaris*). Further data from long-term monitoring are needed to establish tighter relationships.

**ACKNOWLEDGEMENTS**

The research project financed by the Commission of European Communities (Contract No. MED93/19) was to examine squid-jigging with lights as attraction in an effort to find an alternative method to exploit squid, given the proposed outlawing of the beach-seine after 2002. The data on air temperature, wind and rainfall were supplied by the Greek National Meteorological Service. The authors thank Messrs G. Mirokefalitakis (Meteorological Station, Kavala), G. Kornaros and N. Karadarakis (both National Meteorological Service, Athens), for their assistance with extracting the data, and Dr K. Nittis (National Centre for Marine Research, Athens) for his help in processing of wind data. Valuable comments were made on an earlier draft by two anonymous reviewers and also on the analytical method by Mr M. J. Roberts (Sea Fisheries, Cape Town).

**LITERATURE CITED**


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