Sardine (Sardina pilchardus) egg abundance at station L4, Western English Channel, 1988–2008

S. H. COOMBS1*, N. C. HALLIDAY1, D. V. P. CONWAY1 AND T. J. SMYTH2
1MARINE BIOLOGICAL ASSOCIATION, CITEADEL HILL, PLYMOUTH PL1 2PB, UK AND 2PLYMOUTH MARINE LABORATORY, PROSPECT PLACE, THE HOE, PLYMOUTH PL1 3DH, UK

*CORRESPONDING AUTHOR: shc@mba.ac.uk

Received March 23, 2009; accepted in principle June 1, 2009; accepted for publication June 7, 2009

Corresponding editor: Mark J. Gibbons

Results from sampling for sardine (Sardina pilchardus) eggs at station L4 in the coastal Western English Channel over the period 1988–2008 are presented and discussed in relation to environmental conditions. As previously observed in this area, there is a summer spawning season (mid-March to early July) and one in the autumn (early September to mid-November). The historical trend for increasing autumn spawning has continued. The mean spawning temperatures were 12.6 and 14.5°C for the summer and autumn seasons, respectively. Temperature was negatively correlated with summer egg abundance and positively with autumn egg abundance. A negative correlation between egg abundance and the North Atlantic Oscillation index suggested a link between egg numbers and plankton production.

INTRODUCTION

Sardine (Sardina pilchardus, also commonly known as the pilchard) is widely distributed in the eastern North Atlantic from west Africa to the North Sea. It is a short-lived, planktivorous species characterized by periodic localized population fluctuations, which have been associated with changing environmental conditions (e.g. Alheit and Hagen, 1997).

The distribution and abundance of sardine eggs in the Western English Channel has been the focus of a number of studies, including their broad-scale distribution (e.g. Haynes and Nichols, 1994; Coombs et al., 2005) and time-series results since the 1930s at station L5 (approximately 10 miles off Plymouth; Southward et al., 2005). The variations in monthly abundance of eggs from the summer (March–July) and autumn spawnings (September–November) at L5 have been related to hydro-climatic changes throughout the English Channel (e.g. Southward et al., 2005). However, sampling at L5 has been rather sporadic since the late 1980s.

Here, we present results on sardine egg abundance from a more inshore site, station L4 (approximately 4 miles off Plymouth), which has been sampled relatively consistently at weekly intervals since 1988.

METHOD

Sampling at station L4 (50°15.0’N 04°13.0’W, 55 m water depth) has been carried out at weekly intervals, weather permitting, since early 1988. Plankton sampling was conducted by vertical hauls from near bottom to the surface using a 0.57 m diameter, 200 μm mesh WP2 style ring net. Preservation of the samples was in buffered 4% sea water formaldehyde solution, with subsequent analysis in the laboratory for zooplankton and sardine eggs. Usually, two plankton hauls were taken on each sampling occasion, the final estimate of abundance being the mean of these two samples expressed as numbers per square metre of sea surface.


© The Author 2009. Published by Oxford University Press. All rights reserved. For permissions, please email: journals.permissions@oxfordjournals.org
Temporal patterns in sardine egg abundance were assessed from a contour plot of abundance by week produced with Surfer using default plot settings. Missing data points (representing 11.5 and 17.5% of potentially sampled weeks in the main summer and autumn spawning periods, respectively) were interpolated from the long-term mean abundance for a particular week, adjusted proportionately to abundance for the remainder of the spawning season in that year, the summer and autumn spawning seasons being treated separately. A single exceptionally high value in May 1988 was replaced by the mean value for that week.

A linear correlation analysis was carried out in Excel between annual/seasonal abundance of sardine eggs at L4 and the following parameters (Table I): copepod abundance at L4; sea surface temperature at L4; sardine egg abundance at station L5 (50°11.0'N 04°18.0'W, 65 m water depth); North Atlantic Oscillation (NAO) index; English Channel sardine landings.

### RESULTS

#### Annual and seasonal abundance

The overall pattern of annual and seasonal abundance of sardine eggs at station L4 is shown in Fig. 1. The summer spawning season is mainly from mid-March to early July (weeks 12–28), with a peak at the end of May (week 22; Fig. 2); the autumn season is slightly shorter, mainly from early September to mid-November (weeks 36–47), and has a sharper peak of abundance in mid-October (week 42). Numbers of summer spawned eggs were quite variable from year to year, with no evidence of long-term trend, the most notable feature being the three consecutive years of very low summer abundance from 2005 to 2007 (Fig. 3); in contrast, for autumn-spawned eggs there was a trend of increasing abundance with markedly high numbers being recorded in the most recent years (2006–2008).

The sampling period, mean abundance of summer and autumn spawned eggs was 41.3 and 51.9 m⁻² respectively, and 45.6 m⁻² for the complete year.

#### Spawning temperatures

Abundance weighted mean spawning temperatures at L4 were 12.6 and 14.5°C for the summer and autumn seasons, respectively; the corresponding inter-quartile ranges in which 50% of the eggs were found were 10.8–14.2 and 13.7–15.7°C.

#### Environmental relationships

Sardine egg numbers at L4 were significantly correlated (P < 0.01) with those at L5 for the summer season, but there was no relationship between the two corresponding sets of autumn egg numbers (Table II).

Sea surface temperature at L4 was negatively correlated with summer egg abundance and positively with autumn egg abundance (both significant at P < 0.05; Fig. 4). A similar pattern of significant negative correlation with sea surface temperature at L4 was also present in the summer L5 egg data, but any temperature relationships for L5 autumn eggs were negligible.

The annual NAO index was negatively related (P < 0.01) to annual egg abundance at L4, and similarly, but not significantly, throughout most of the other L4 and L5 egg measures. Copepod abundance from January to July at L4 was positively correlated (P < 0.01) with L4 summer egg numbers only. There was a weak negative relationship between English Channel landings of adult sardine and autumn egg numbers at L4, but a weak positive relationship at L5.

### Table I: Datasets used in the correlation analysis of sardine eggs at L4 for the period 1988–2008

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station L5 monthly sardine egg abundance (numbers per standard haul of ~5000 m³); annual, summer and autumn seasons</td>
<td>Update (N. Halliday, Personal communication) of Southward and Boalch (1988)</td>
</tr>
<tr>
<td>Station L4 weekly surface temperatures (°C); annual, summer and autumn means</td>
<td>In situ CTD data interpolated onto a consistent weekly grid</td>
</tr>
<tr>
<td>North Atlantic Oscillation (NAO) index; annual and winter (December–March) means</td>
<td>NOAA Climate Prediction Centre, <a href="http://www.cpc.noaa.gov/products/precip/cwlink/pna/nao.shtml">www.cpc.noaa.gov/products/precip/cwlink/pna/nao.shtml</a></td>
</tr>
<tr>
<td>Annual English Channel (ICES areas VIII and e) sardine fishery landings (tonnes)</td>
<td>UK statistical tables, <a href="http://www.mfa.gov.uk/statistics/uksea%EF%AC%81sh.htm">www.mfa.gov.uk/statistics/ukseaﬁsh.htm</a></td>
</tr>
<tr>
<td>Station L4 copepod abundance (numbers m⁻²); annual, summer and autumn means</td>
<td>L4 data archive, <a href="http://www.westernchannelobservatory.org.uk/14/data">www.westernchannelobservatory.org.uk/14/data</a></td>
</tr>
</tbody>
</table>
DISCUSSION

Abundance of sardine eggs at the inshore station L4 (mean of 45.6 m$^{-2}$, equivalent to 0.91 m$^{-3}$ over the 50 m haul depth) was higher than further offshore at L5 (mean of 26.2 m$^{-2}$, equivalent to 0.41 m$^{-3}$ over the 65 m haul depth), but less than from CPR sampling throughout the English Channel (1.23 m$^{-3}$; Coombs et al., 2005). Considering the different sampling methods and the variability of egg distribution, often with localized inshore concentrations (e.g. Haynes and Nichols, 1994), these are comparable values. While the increasing trend towards autumn spawning was paralleled in both the L4 and L5 data, and supported in CPR data (Coombs et al., 2005), the high year-to-year variability inherent in single station sampling reduced the potential for any close correlation between L4 and L5 egg abundance.

The number of fish eggs spawned is typically a reflection of stock size. Hence, the higher overall numbers of sardine eggs at L4 in recent years, mostly due to increased autumn spawning, implies higher stock levels. However, sardine is a widely distributed species and in the English Channel, the population is possibly migratory and may be part of a wider population through Biscay and the more recent extension into the North Sea (Beare et al., 2004; Alheit et al., 2007). Furthermore, in the Channel, there are no annual stock estimates and landing data only, which are an imperfect measure of stock abundance for a periodically targeted species. Considering the reported catch data in the western Channel over the period 1988–2007, these were relatively high from 1992 to 1995 and rather low from 2003 to 2007, which has little relationship with egg numbers at L4.

Sardine populations near the northern limit of their range in the English Channel, as elsewhere, have fluctuated over historical time-scales. In the Western English Channel, sardine has dominated over the more cold-water-adapted herring (Clupea harengus) in warmer periods (Alheit and Hagen, 1997). Similarly, the increase in adults caught in the North Sea since 1995 and the presence of eggs in the German Bight have both been related to rising sea temperatures (Beare et al., 2004; Alheit et al., 2007). Over much of the previous century, variations in numbers of sardine eggs at Station L5 off Plymouth have been related to secular changes in temperature. Periods of increased egg abundance peaking in 1940, 1958 and 1967/1968 and since 1995, at least, have coincided with warmer periods. During intervening colder periods, overall egg numbers have been lower, with a greater proportion of spawning in the relatively warmer autumn season compared with the spring/summer (Southward et al., 2005). This autumn dominance has accelerated in recent years at both L4
Table II: Correlation matrix for sardine egg abundance, with the 5 and 1% significance levels indicated by one or two stars, respectively

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>L4 eggs all year</th>
<th>L4 eggs summer</th>
<th>L4 eggs autumn</th>
<th>L5 eggs all year</th>
<th>L5 eggs summer</th>
<th>L5 eggs autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>L4 eggs summer (Jan–July)</td>
<td>21</td>
<td>0.326</td>
<td>-0.416</td>
<td>-0.059</td>
<td>0.030</td>
<td>0.724**</td>
<td>-0.643**</td>
</tr>
<tr>
<td>L4 eggs autumn (Aug–Dec)</td>
<td>21</td>
<td>0.724**</td>
<td>-0.047</td>
<td>-0.643**</td>
<td>0.013</td>
<td>0.277</td>
<td>0.416</td>
</tr>
<tr>
<td>L5 eggs all year</td>
<td>8</td>
<td>0.013</td>
<td>0.270</td>
<td>0.468*</td>
<td>0.142</td>
<td>0.085</td>
<td>0.244</td>
</tr>
<tr>
<td>L5 eggs summer (Jan–July)</td>
<td>10</td>
<td>-0.162</td>
<td>0.732**</td>
<td>-0.351</td>
<td>0.127</td>
<td>-0.035</td>
<td>0.606**</td>
</tr>
<tr>
<td>L5 eggs autumn (Aug–Dec)</td>
<td>10</td>
<td>0.085</td>
<td>-0.244</td>
<td>0.236</td>
<td>0.466*</td>
<td>0.013</td>
<td>0.671</td>
</tr>
<tr>
<td>Temperature (all year)</td>
<td>21</td>
<td>-0.010</td>
<td>-0.466*</td>
<td>0.330</td>
<td>-0.313</td>
<td>-0.398</td>
<td>-0.305</td>
</tr>
<tr>
<td>Temperature (Jan–July)</td>
<td>21</td>
<td>-0.193</td>
<td>-0.387</td>
<td>0.270</td>
<td>-0.238</td>
<td>-0.361</td>
<td>-0.385</td>
</tr>
<tr>
<td>Temperature (Aug–Dec)</td>
<td>21</td>
<td>0.157</td>
<td>-0.435</td>
<td>0.468*</td>
<td>0.166</td>
<td>0.486*</td>
<td>-0.435</td>
</tr>
<tr>
<td>NAO annual</td>
<td>21</td>
<td>-0.488*</td>
<td>-0.013</td>
<td>0.468*</td>
<td>-0.388</td>
<td>-0.385</td>
<td>-0.435</td>
</tr>
<tr>
<td>NAO winter (Dec–Mar)</td>
<td>21</td>
<td>-0.277</td>
<td>0.166</td>
<td>-0.388</td>
<td>0.486*</td>
<td>-0.385</td>
<td>-0.435</td>
</tr>
<tr>
<td>Copepods (Jan–July)</td>
<td>21</td>
<td>0.142</td>
<td>0.606**</td>
<td>-0.305</td>
<td>0.127</td>
<td>-0.385</td>
<td>0.299</td>
</tr>
<tr>
<td>Copepods (Aug–Dec)</td>
<td>21</td>
<td>-0.075</td>
<td>0.383</td>
<td>-0.385</td>
<td>0.127</td>
<td>-0.398</td>
<td>0.299</td>
</tr>
<tr>
<td>Copepods (all year)</td>
<td>21</td>
<td>0.044</td>
<td>0.566*</td>
<td>-0.370</td>
<td>0.387</td>
<td>0.458*</td>
<td>0.964**</td>
</tr>
<tr>
<td>Channel sardine landings</td>
<td>20</td>
<td>-0.276</td>
<td>0.268</td>
<td>-0.458*</td>
<td>0.592</td>
<td>0.685*</td>
<td>0.499</td>
</tr>
</tbody>
</table>

Significance values vary due to differing numbers of data points (n).

Fig. 4. Relationship between mean temperature in each spawning season and summed egg abundance for summer and autumn spawned sardine eggs at station L4 for the years 1988–2008.

and L5, yet temperatures have continued an upward rise, at variance with previous conclusions. Compounding this is the negative relationship between egg abundance and temperature at L4 during the summer and the positive relationship in the autumn. During a period of secular warming trend, this would account for the observed decline in summer spawning and increase in the autumn.

The 50% range of spawning temperatures at L4 of 10.8–14.2°C for the summer season and 13.7–15.7°C for the autumn are consistent with the 50% all-year range of 13.0–14.7°C for L5 (Coombs et al., 2006). The different seasonal temperature preferences at L4 imply two different groups of spawning fish, but no data are available to distinguish whether they are distinct populations, are split by age composition or are the same fish spawning in the autumn having acclimatized to warmer temperatures over the summer.

The NAO atmospheric pressure index has been widely used as a broad-scale environmental indicator, with the winter index being related to sardine catches and recruitment (e.g. Alheit and Hagen, 1997; Guisande et al., 2004) and to plankton in the North Atlantic and English Channel (Beaugrand et al., 2000). At both L4 and L5, there was a fairly consistent negative relationship between sardine egg numbers and the NAO (but significant only for the annual index at L4). While this indicates some link between sardine spawning and atmospheric circulation, the precise mechanism remains speculative (and not necessarily consistent across the range of different sardine spawning environments), whether due to direct oceanographic influence (e.g. temperature) or mediated via some aspect of plankton production.

Plankton feeders, such as sardine, are closely linked to the planktonic food web where lipid reserves and food availability have been shown to affect the number of spawnings per year for other small pelagic fish (Hunter and Leong, 1981; Peebles et al., 1996). While summer egg numbers at L4 were related to copepod levels, there is no similar relationship to explain the increasing trend of autumn spawning. One relevant observation is that in recent years at both L4 and L5, the intensity of the late summer/autumn plankton bloom, as measured by chlorophyll concentration, has greatly exceeded the spring bloom (Smyth et al., 2010). This would favour accumulation of nutritional reserves in adult sardine for gamete production prior to autumn spawning. Furthermore, copepod abundance is, on average, 20% higher in the autumn at L4 than in the summer and thus favourable for autumn spawning.

ACKNOWLEDGEMENTS

Acknowledgements are due to the crew of the Plymouth research boats for collection of the samples.
and to Roger Harris for making the L4 samples available for sardine egg analysis.

**FUNDING**

Funding for the MBA participants was provided, in part, from the NERC Oceans 2025 programme.

**REFERENCES**


