ON THE PROBLEM OF IDENTIFYING AND ASSESSING POPULATIONS OF FALKLAND ISLAND SQUID *LOLIGO GAHI*

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Patterns of catches of *Loligo gahi* around the Falkland Islands in the years 1982-1986 initially suggested a simple population structure with one stock peaking in the fishery in autumn and another peaking in spring. Management of two seasons was therefore imposed in 1987. This pattern has proved highly variable, with the result that, for some years, it seems as if up to four cohorts are present in two separated northern and southern fishing areas. In this paper, evidence from fishing vessel and scientific observer data is examined for these different population structures. The conclusion is that the simplest structure that fits the observed data is of two main cohorts recruiting during a year to a single fishing area, albeit with considerable geographic heterogeneity, with a smaller recruitment episode sometimes present at the end of the year. The recruitment of these cohorts to the fishery is not, however, coincident with current management seasons.

Loligo gahi, the Patagonian longfin squid, has been the subject of a major trawl fishery since 1982 (Csirke 1987). In common with other *Loligo* species, *Loligo gahi* has an annual life cycle (Patterson 1988, Hatfield 1991). It is thought to spawn in shallow water, juveniles migrating offshore into deeper water to feed, then returning to shallow water to breed (Hatfield *et al.* 1990, Hatfield and Rodhouse 1994a).

When the Falkland Islands Fisheries Department (FIFD) was established in 1987, two fishing seasons were defined for *Loligo gahi*. This decision was based on the examination of 1984–1986 fisheries data which revealed autumn and spring peaks in catches. The seasons currently run from February to May and from August to October inclusive. The fishery takes place within a defined "*Loligo* box", which lies within the Falkland Islands Interim Conservation and Management Zone (see Fig. 3 later).

Annual assessments of squid stocks around the Falkland Islands have been performed on behalf of the FIFD by the Renewable Resources Assessment Group (RRAG) at Imperial College, London (FIFD 1989). Assessments of *Illex argentinus* around the Falkland Islands made using Delury depletion models have proved to be complex but tractable (Beddington *et al.* 1990, Rosenberg *et al.* 1990, Basson *et al.* 1996). In contrast, assessments of *Loligo gahi* have often presented problems, largely because the pattern of depletions in each season is quite variable. Agnew *et al.* (1998) were able to fit Delury depletion models to only 75% of the first and second seasons between 1987 and 1996, and developed alternative assessment approaches to deal with this situation. This paper briefly extends their work, exploring both the temporal and spatial biological complexities which exacerbate the difficulties of assessing *Loligo gahi*.

METHODS

Detailed daily catch and effort data have been collected by FIFD from the fishery since 1987. FIFD has also implemented a comprehensive observer programme, which has collected biological data from the fishery during each fishing season since 1987. Data from the fishery in 1982-1986 are available from a number of sources (MRAG 1986, Csirke 1987, Patterson 1988), but they are not sufficiently detailed to enable stock size to be assessed (only catch data are available, and only on a monthly basis).

Agnew *et al.* (1998) described in some detail the use of Delury depletion models (Rosenberg *et al.* 1990) to assess *Loligo gahi* for the years 1987–1996. These analyses are not repeated here. This paper contains largely descriptive analyses of catch and biological data from the fishery. Although catches of *L. gahi* have been made from all around the Falkland Islands, more than 98% of those made since 1987 have been within a box defined by 50°00´-53°30´S and 56-61°W. This is the area that contains the current licensed fishery. In order to eliminate data that may have originated from other stocks on the Patagonian shelf (a possibility suggested by Wysokiński 1996),

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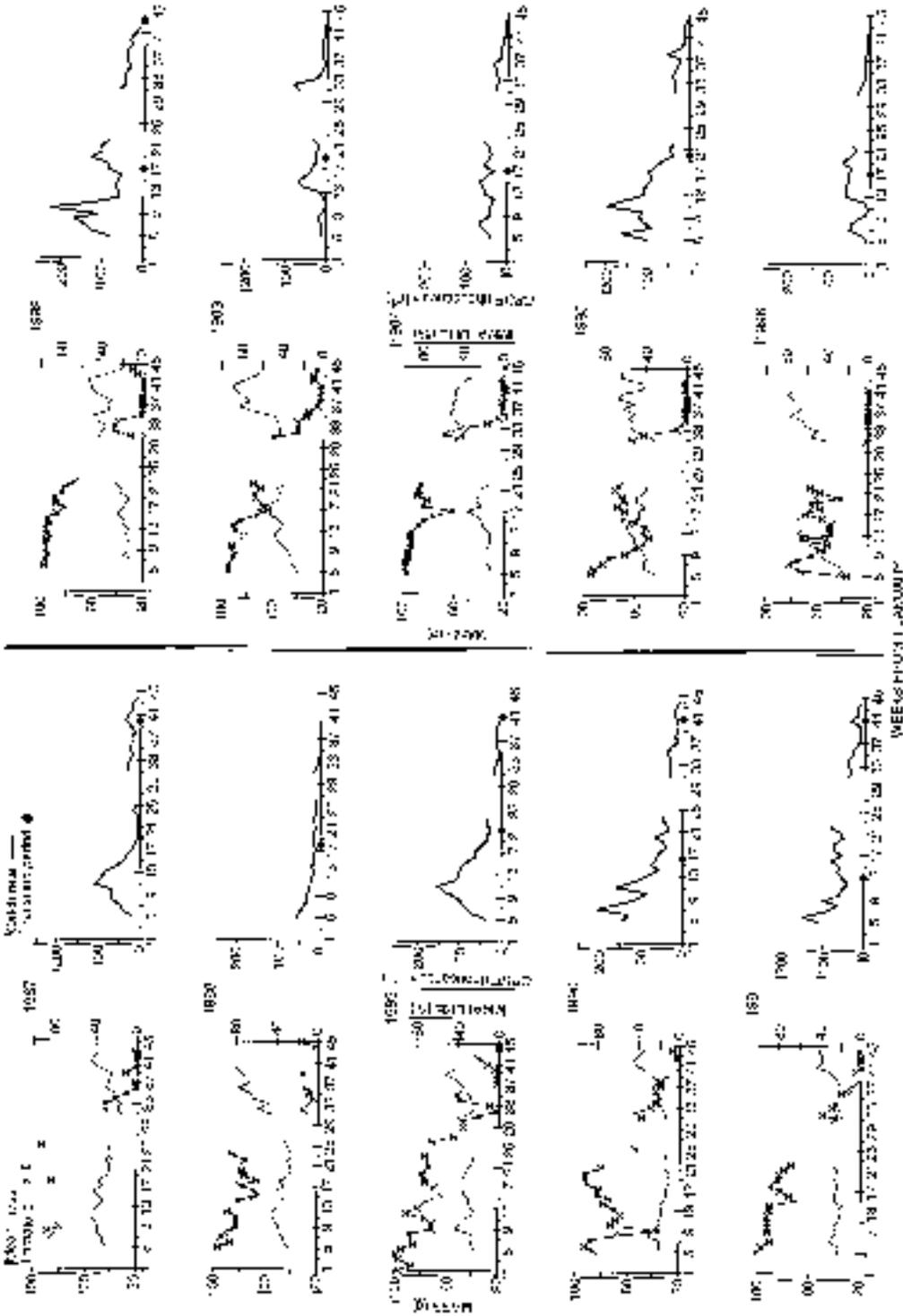 University of Warwick, Coventry CV4 7AL, United Kingdom

Fig. 1:   Graphs on left show mean mass of *Loligo gahi* and the percentage of immature squid (the percentage of animals of both sexes having Lipiński's 1979 maturity of 1–2) by week. The diamonds indicate the assumed first week that a new cohort is dominant in the fishery during a transition period, estimated from consideration of mean mass, maturity and length frequency data (see

all analysis was restricted to this box.

Units of time were periods of seven days following the 1st of January. Thus, March begins in Week 9, May begins in Week 18, August begins in Week 31 and October in Week 40. Weekly length frequency data were used in combination with land-based measurements of the length-mass relationship for a particular season to calculate mean mass per week. The proportion of immature animals in observer samples was calculated as the proportion of squid of maturity stage 1 and 2 on Lipiński's (1979) scale.

Loligo gahi are thought to recruit to fishing grounds over a period of some weeks, subsequently being resident on the grounds during a time in which the population is effectively closed and can be assessed using depletion methods (Agnew *et al.* 1998). Eventually they are thought to leave the fishing grounds to spawn, being replaced by another recruiting cohort in a "transition event". This hypothesis was investigated, identifying transition events as times when trends in length frequency, mean mass and maturity were reversed. For instance, a resident population should show a trend of increasing mass, increasing maturity, and length frequency distributions whose mode is trending to greater lengths. When these trends reverse a transition event is taking place. Figure 1 shows transition events as diamonds at the point where, subjectively using all available *cpue* and biological data, it was judged that the incoming cohort became dominant in catches.

RESULTS

Temporal factors

Plots of maturity and mass at week show large variation but generally conform to the hypothesis of a cohort recruiting in the early part of the year, remaining resident on the fishing grounds for about 10 weeks (Fig. 1). That cohort is replaced during a transition event by a new one which then remains in the fishery until very late in the year, growing to a much larger size than the first. In some years, this second cohort also seems to be replaced in a transition event around Week 40 (e.g. in 1987, 1989 and 1993). The transition event in the first season is usually around Week 17, but the timing is quite variable.

Plots of catch rate (*cpue*) show several distinct patterns (Fig. 1). In the first season, *cpue* may initially rise, as the first cohort recruits to the fishery, and then decline as it is fished while resident on the fishing grounds. In some years recruitment to the fishery is obviously earlier than Week 5, and the *cpue* is already
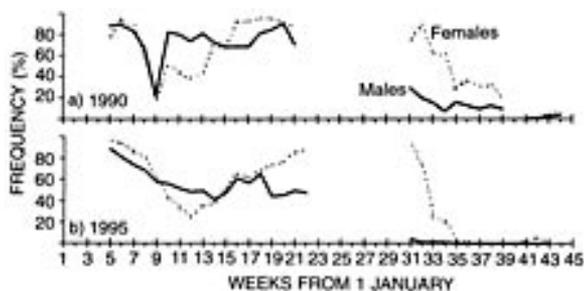

Fig. 2: Percentage of *Loligo gahi* males and females that were immature (Lipiński's 1979 maturity scale 1–2) in (a) 1990 and (b) 1995

in decline when the fishery starts. In most years, *cpue* reaches a low point and then starts to increase, consistent with the hypothesis that this is the transition period between first and second cohorts. Quite often, however, this increase is very slight, so that the catch rate is apparently constant. This would be consistent with a situation where the second cohort was recruiting so slowly that immigration was effectively equal to removals by fishing. In 1993, recruitment of the first cohort and the rise in *cpue* appears to have been extremely late. The years 1994 and 1996 display extremely odd patterns of catch rate, and although the biological data suggest a transition at Week 17, this is not well reflected in the *cpue* series.

In the second season, *cpue* usually displays a slow decline. In those years that a transition around Week 40 is evident from biological data, the catch rate does not usually show a very great or prolonged increase. It is assumed from this latter point that, even though Agnew *et al.* (1998) could not assess the third cohort, it is of relatively small size compared with the first two cohorts.

When trends in *cpue* are compared with the biological data in Figure 1, it is clear that there is often coincidence between the first season trough in catch rate and transition times suggested by biological data. In some years, however (e.g. 1990 and 1995), the percentage of immature animals starts to rise while *cpue* is declining. This would imply that recruitment of the second cohort does not necessarily take place at the same time as dispersion of the existing cohort. In the case where the percentage of immature animals starts to increase on a declining *cpue* curve, it could be postulated that the event was primarily one of mature adults leaving the population. Conversely, when catch rate is rising, it could be postulated that a new cohort is recruiting to the fishery.

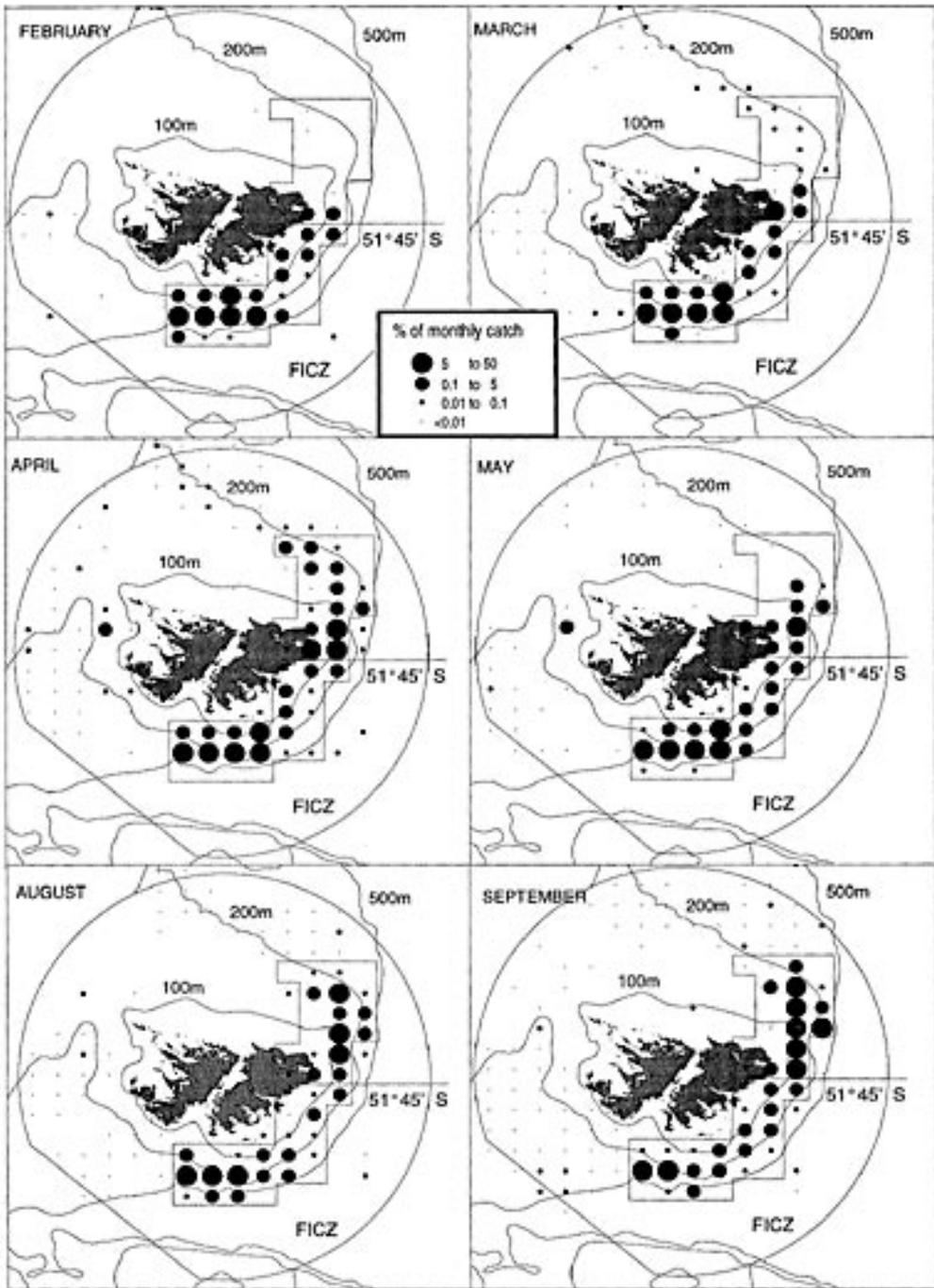Determination of transition periods from maturity

Fig. 3: Distribution of catch proportions of *Loligo gahi* in 1992, 1993, 1994 and 1996. These are the most recent years in which there has been a significant fishery in the northern area. The *Loligo* box, the Falkland Islands Interim Conservation and Management Zone (FICZ) and the 51°45´S line which is used in this paper to separate the northern and southern fishing areas, are all shown

data is further complicated by the behaviour of males and females. Although it is well known that males mature earlier than females (Hatfield and Rodhouse 1994b), there are sometimes substantial differences in the trends of male and female maturity with time, which suggest that there may be differences in the timing of migration of the two sexes. Figure 2 shows male and female maturity plots for the two unusual years identified in the previous paragraph. In 1990, with the exception of Week 9, the male population appears to become more mature while the female population is becoming less mature. As males mature earlier than females, this apparent inconsistency with the hypothesis of an incoming immature second cohort might be explained by an unusually early maturation of males in 1990. In 1995, both males and females show evidence of an incoming second cohort, but it seems to be about 2 weeks later for males than for females. These observations do not invalidate the overall hypothesis of two major cohorts per year, but they do make the correct identification of transition events, and subsequent assessment of the individual cohorts, more difficult.

The high degree of variability in the trends in biological and *cpue* data obviously makes assessment by depletion methods difficult. Agnew *et al.* (1998) only achieved success when they applied the depletion assessment separately to the first and second cohorts, rather than the first and second seasons. Even so, they were only able to estimate cohort sizes for all years once they had developed an extended Delury method, which modelled trends in catchability over time, to cope with *cpue* trends that could not be modelled by a simple Delury on its own.

Spatial factors

The Falkland Islands fishery for *Loligo* takes place to the south and east of the islands, and the bulk of the catches are taken within a management area called the *Loligo* box. Most early years saw the bulk of catches being taken in the south of the *Loligo* box, but recently there has been a tendency for the fishery to extend into the north of the box. Figure 3 reveals that fishing at the start of the first season has been concentrated in the southern half of the box, extending to be more or less equally divided between northern and southern parts from April onwards. Although Carvalho and Pitcher (1989) failed to detect genetic differences between any Falklands *Loligo* "stocks", Nolan *et al.* (in prep.) have recently detected significant differences in size between research samples taken in the northern and southern areas. Although these differences may result solely from differences in food availability and/or temperature regime, and are

probably not informative as to the genetic stock structure of the population, they may be important for the definition of management units. The question therefore arises as to whether the two areas are distinct from a management point of view.

Figure 4 shows *cpue* separated by northern and southern areas (north and south were separated at 51°45´S, marked on Fig. 3). The pattern of catches described above restricts data availability from the northern area. However, for most of the occasions when there are data from both the north and the south, Figure 4 shows that patterns of *cpue* are similar. The exceptions are 1988 and 1993. In 1988, the catch rate in the northern area was extremely low. Pairwise *t*-tests were performed for *cpue* averaged over the whole of the southern and northern areas and then compared by week. 1988 was the only year for which these tests detected a significant difference between *cpue* in the north and south ($t = 6.64$, $n = 16$, $p < 0.001$). Figure 4 does present some evidence of a recruitment pulse taking place in the north in June and July 1993, but lack of data from between the first and second seasons prevents examination of whether this was actually a recruitment pulse, and whether it was restricted to the northern area.

Lack of observer data from the northern area also frustrates any attempt to examine differences in the timing of changes in maturity proportion between the two areas. Comprehensive maturity data are generally only available from the second season, when fishing in the northern area is more predictable. There is generally a steady decline in the proportion of young animals in both zones at the start of the second season (Fig. 1). Pairwise *t*-tests, comparing arcsine-transformed proportions of immature animals (arcsin $\sqrt{proportion}$) by week in the northern and southern areas, were performed on males and females separately, for the eight second seasons for which there were sufficient data (1989–1996). Although sample sizes were small (there were often fewer than 10 coincidentally sampled weeks in a year), significant differences between the northern and southern areas were detected only for one out of the 16 data sets, males in 1995 ($t = 2.58$, $n = 9$, $p < 0.05$).

There are two hypotheses for the differences between north and south noted by Nolan *et al.* (in prep.). They could be independent stocks, or the differences could simply be attributable to uneven distribution of a single stock. The similarity in patterns of *cpue* between north and south suggest one stock with geographic heterogeneity. Figure 3 suggests that the northern extension of fishing actually follows the 200 m contour, and perhaps this reflects the distribution of *Loligo* in relation to ecological dynamics, such as for instance changing prey abundance. Maturity data do not suggest differences in spawning time between the two areas.
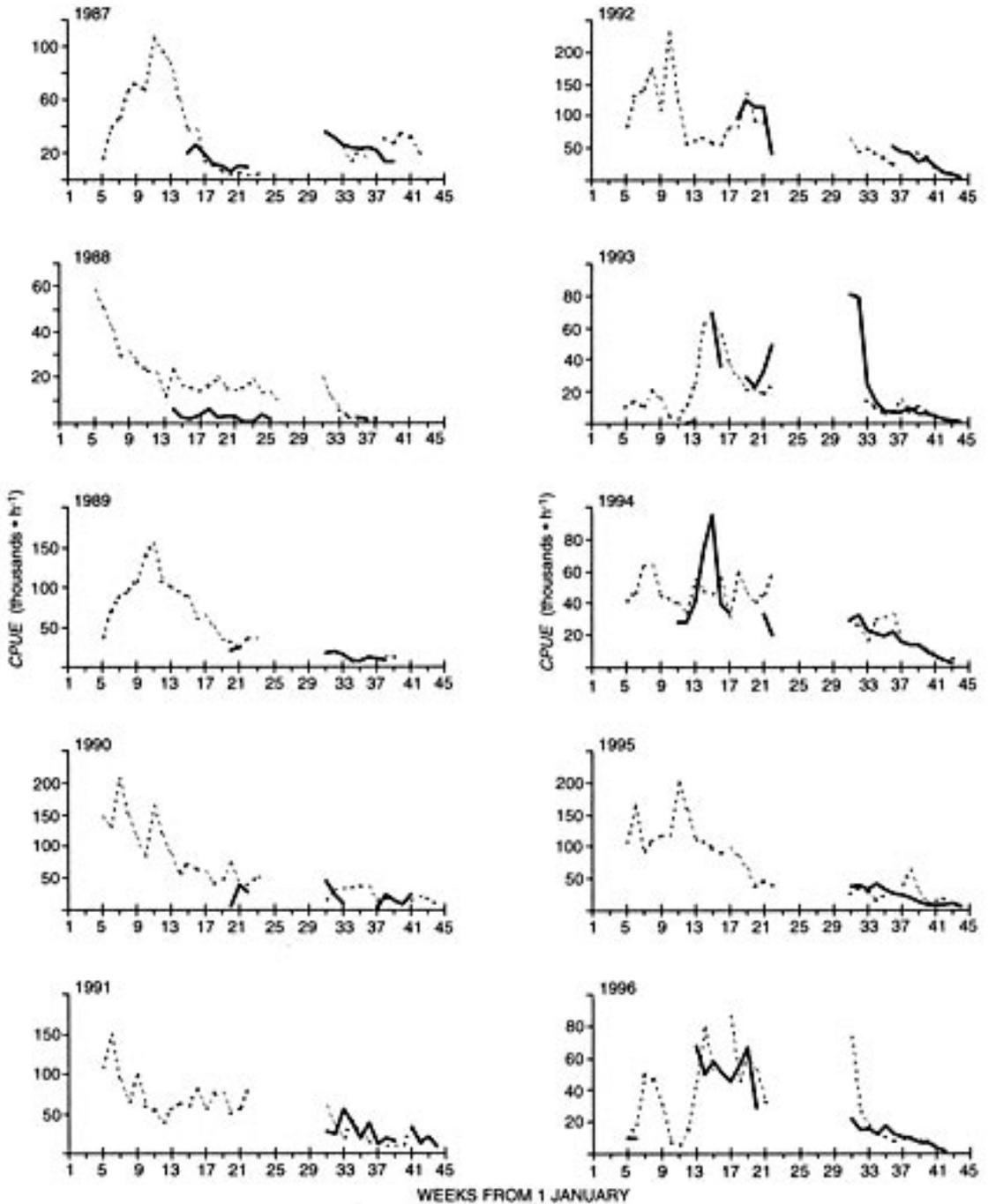
Fig. 4: Catch rate of *Loligo gahi* in the northern area (solid line) and in the southern area (dashed line) of the fishery around the Falkland Islands. Area definitions are shown in Figure 3. Weeks with fewer than 40 hours fishing are excluded

DISCUSSION

A number of studies (Patterson 1988, Hatfield 1996, Agnew *et al.* 1998) have hypothesized that usually two but up to three *Loligo gahi* cohorts recruit to the Falkland Islands fishery over a calender year, one in January, one in April/May and sometimes one in September/October. The results above confirm this conclusion. Other studies have shown that two cohorts occur, or are likely to occur, in many *Loligo* fisheries (Augustyn *et al.* 1992, Brodziak and Rosenberg 1993, da Cunha and Moreno 1994, Porteiro 1994, Grist and des Clers 1997).

There is still a major gap in knowledge of cohort structure occasioned by the closed season and lack of data in June and July. It is, for instance, possible that the bulk of the second season catches may be from a cohort that recruits in the June/July period, and not from the one recruiting in April/May – i.e. that there are up to four cohorts per year. The results above indicate that the simplest model of population structure which fits the data available at present is one of two major cohorts per year of a single stock covering both the northern and southern areas, sometimes with a third small recruitment period in October.

Further evidence for the continued presence of the second cohort on the fishing grounds throughout the closed season is the striking relationship between the *cpue* at the end of the first season and the total catch of the presumed second cohort (Fig. 5: correlation coefficient 0.876, *n* = 10). This does not rule out the possibility that in some years there may be more than three recruitment periods, or that in some years the northern and southern parts of the stock may behave differently. What it does mean is that in general the cohorts behave independently, each having separate spawning and recruiting times within an annual life cycle (Hatfield and Rodhouse 1994a). It is not clear at this stage whether the occasional third recruitment episode is late recruitment to the second cohort, a cohort in its own right, or an early recruitment of the following year's first cohort. Fisheries and research data from November to January and June to July are required to shed further light on these questions.

Grist and des Clers (1997) have shown that individual-level physiological responses to relatively small temperature fluctuations may substantially affect squid population structure. It may be that long-term cycles in water temperature might change the number and timing of recruitment episodes by the same mechanism, which would explain the considerable variation in peaks of *cpue* seen in Figure 1.

The biological and theoretical analyses that have been undertaken recently (Hatfield and Rodhouse
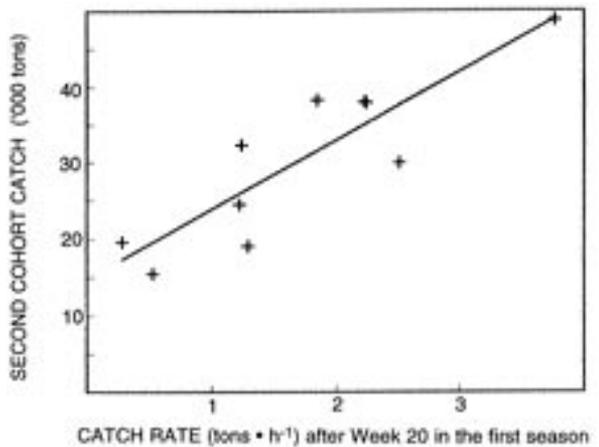

Fig. 5: Catch rate of all vessels fishing for *Loligo gahi* after Week 20 in the first season, plotted against the total catch of the second cohort. The second cohort was presumed to be the target of the fishery after the week of transition indicated in Figure 1. The regression line is catch ('000 tons) = 14.8 + 9.1 *cpue*, *r* = 0.876, *n* = 10

1994a, b, Hatfield 1996, Grist and des Clers 1997, Agnew *et al.* 1998) have made significant progress in understanding the behaviour and migration patterns of Falkland Islands *Loligo*. There is now a much clearer understanding how cohorts grow and recruit to the fishery. The 2/3-cohort model is sensible and useful in that it has permitted coherent assessments to be carried out and has led to the identification of stock-recruit relationships and biological reference points such as minimum escapement biomass (Agnew *et al.* 1998). Under this model, recruitment to the fishery is not coincident with current management seasons, and this may have serious implications for management.

There remains a need for a model to explain the various patterns of *Loligo gahi* recruitment and cohort timing. Such a model would make use of the water-temperature based hypotheses of Grist and des Clers (1997) as well as the approaches to incorporation of migration events into Delury assessments made by Brodziak and Rosenberg (1993). Future assessments of *Loligo gahi* will probably still be based on Delury models, supplemented by the extended Delury approach of Agnew *et al.* (1998). However, a Bayesian approach may well provide a more robust assessment (McAllister and Kirkwood 1998) than simple application of a Delury. Such approaches are also being developed for the South African chokka squid *Loligo vulgaris reynaudii* fishery (B. A. Roel, Sea Fisheries, Cape Town, pers. comm.).

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