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Fen raft spider recovery project: a decade of monitoring

Part 1: Report for 1991-1999 Part 2: Report for 2000

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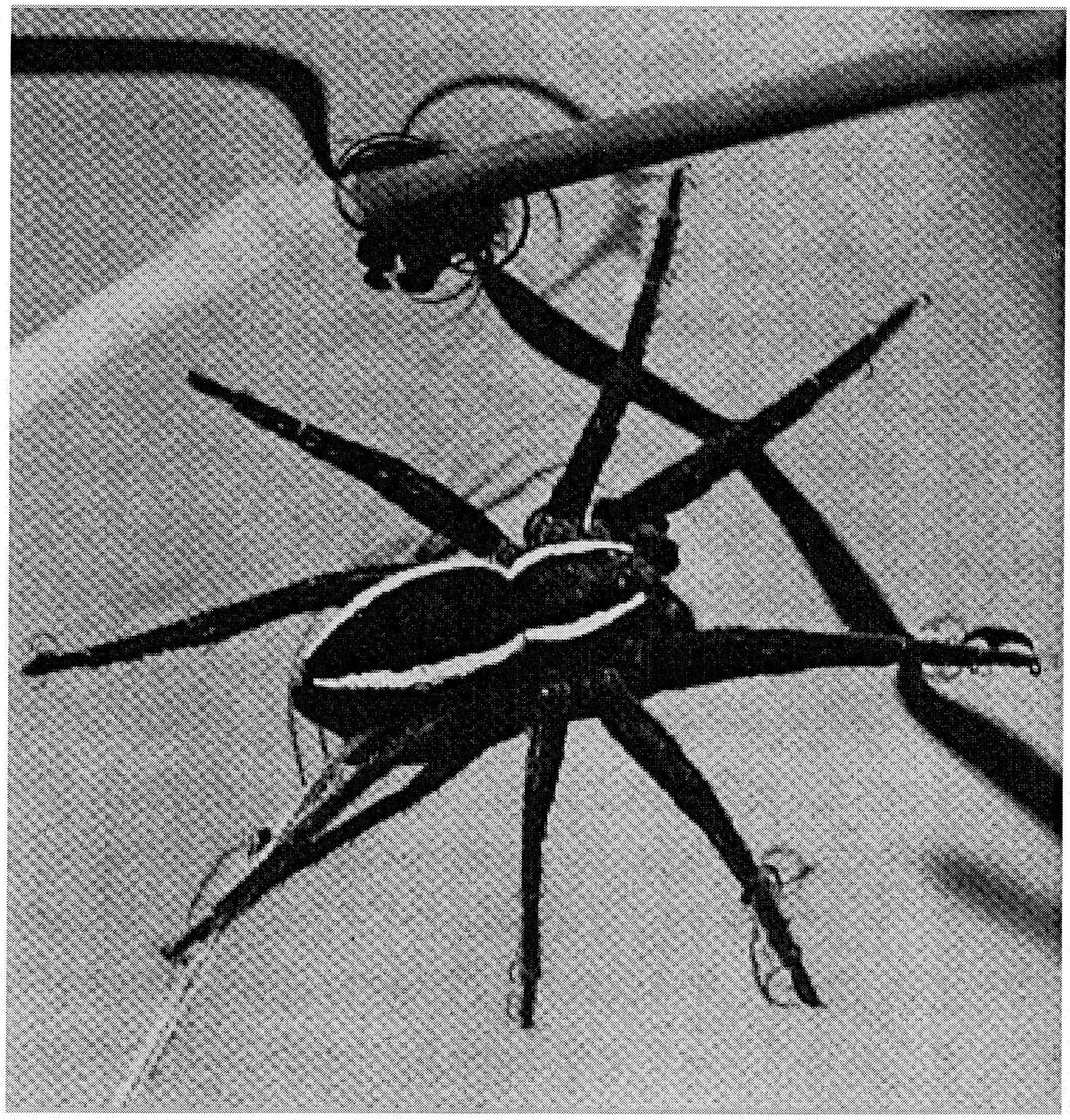

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English Nature Research Reports

Number 358

Fen Raft Spider Recovery Project: A decade of monitoring

Part 1:
Report for 1991-1999

Part 2:
Report for 2000

Part 3:
The status and conservation of the fen raft spider *Dolomedes plantarious* at Redgrave and Lopham Fen National Nature Reserve, England
***Biological Conservation*, 95: pp. 153-164.**

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Contents

Part 1: Report for 1991-1999

1. Introduction

This report describes the results of monitoring and management work completed as part of the Fen Raft Spider (*Dolomedes plantarius*) Recovery Project at Redgrave and Lopham Fen NNR. The first part of the report describes monitoring and management work undertaken in 1999. This was the ninth year in which a systematic census of the spider population was carried out under the Project and analyses are presented of the entire data set, in the form of a draft paper accepted for publication by Biological Conservation, in Appendix 1. The background to the project is described in the paper and further details of previous years work under the project are given by Duffey (1991) and Smith (1992-1998).

July 1999 saw the closure of the artesian bore-hole which had been responsible for degradation of Redgrave and Lopham Fen and reduction of the spider population to its current precariously low levels. The ensuing hydrological recovery of the fen introduces the possibility of radical recovery of the spider population. Because of this, the objectives of the Recovery Project, which to-date have been prevention of extinction of the residual population, can be re-defined. The new objectives are defined in the *D. plantarius* Species Action Plan as a ten fold increase in the range of the population and an increase in density to an average of *c.* 15 spiders per pool, the maximum recorded since 1991. Substantial recovery of the population also introduces possibilities for changing the method of monitoring. The second part of the report covers work done in 1999 towards to development of a new census methodology. The objectives of the new scheme and progress towards development of the methodology are described.

Detailed recommendations are given for the development of both the monitoring and management of *D. plantarius* at Redgrave and Lopham Fen in 2000. The monitoring work was financially supported by English Nature, with help from the SWT, as a contribution to the Species Recovery Programme.

2. Monitoring in 1999

2.1 Methods

2.1.1 *Dolomedes plantarius*

The annual census of *D. plantarius* followed the methodology used since 1993 and described by Smith (1993). The three replicate census rounds for Little Fen were carried out on 17, 18 and 19 July. Those for Middle Fen took two days per round and were carried out between 21 and 26 July.

2.1.2 Water levels

Water levels were measured in all of the census pools at monthly intervals until the beginning of June. From June until the beginning of October the levels were measured every week to facilitate detection of changes resulting from closure of the bore hole. The monitoring frequency was reduced to fortnightly intervals in the Autumn and Winter, when levels were reasonably stable.

2.2 Results

2.2.1 *Dolomedes plantarius*

Analyses of the census data for 1999 are presented with those for the previous eight years in Appendix 1.

2.2.2 Water Levels

Little Fen

High water levels were sustained on Little Fen for most of the 1999 season. As a result of the wet winter of 1998/1999, spring and early summer levels were higher than in any winter since 1994 (see Appendix 1). Dry weather in July resulted in a brief dip below the April 1992 datum but high rainfall in August resulted in rapid recovery to high levels which were sustained throughout the Autumn (Figure 1a).

1999 was the ninth successive year in which water was piped to a line of pools in the core of the spiders range during the summer. Although the 1999 supply started on 16 June, it had little impact on water levels until the volume was increased on 15 July. The irrigated pools then retained high and fairly constant levels, showing little sign of the July or early September lows seen in the unirrigated pools (Figure a). By the time the supply was turned off on 24 September, levels in the unirrigated pools were already as high as those in the irrigated pools. A total of 26.504 Ml water was supplied during the season.

Middle Fen

On Middle Fen, as on Little Fen, winter and spring water levels were high (Fig. 1b). As in previous years, the fluctuations during the summer were more pronounced than on Little Fen but, in general, much higher levels were sustained during the summer than in most previous years. The irrigation supply, from the 15 July onwards, in combination with the high August rainfall, maintained higher and fairly constant levels in the irrigated pools. When the irrigation supply was turned off, the levels in the irrigated pools fell slightly to meet those in the unirrigated pools (Fig. 1b). The drop in levels later in October and November reflected a combination of lower rainfall and a low setting on the sluice controlling the Middle Fen section of the River Waveney.

2.3 Vegetation management

The only management work carried out within the areas occupied by *D. plantarius* in 1999 was rotational cutting of *Cladium mariscus*. The block on Little Fen was cut in mid-August and that on Middle Fen in the last week of July. The areas cut are shown in Figures 2 and 3 for Little Fen and Middle Fen respectively. In addition to the planned area on Middle Fen, a *c* 10 m wide band of sedge was cut in error, adjacent to the fence line north of the spider pools in Compartment 4.

The blocks of *C. mariscus* cut on both Little and Middle Fen were flooded at the time of cutting. The use of heavy machinery to remove the litter caused damage likely to result in death of the sedge, over approximately 10% of area.

Other management operations planned for 1999 were not carried out. These were as follows:

1. Intensive grazing of areas of the sedge beds adjacent to the cut areas. These areas of sedge, which were due for rotational management, were therefore completely unmanaged.

2. Areas of litter and degraded sedge within the spiders range, for which annual, extensive grazing, was planned, were also left unmanaged. On Little Fen, although tarpan horses had access to these areas between 24 June and early December, they did not enter them, preferring to graze drier, grass-dominated areas of the fen. On Middle Fen, Sussex cows has access to the unirrigated pools between 5 July and the first week of January 2000 but had little impact around the pools margins.

3. Winter removal of mud and reed rhizomes from *c.* half of the machine dug pools, within the spiders range on Middle Fen.

Scheduled removal of *Stratiotes aloides* from the Middle Fen pools to which it was introduced in 1996 (Smith 1996) for a three year trial period, was unneccessary because no live plants were found.

2.4 Recommendations for management and monitoring in 2000

2.4.1 Monitoring

1. **Maintenance of current methodology**: the census scheme initiated in 1993 was intended to be maintained until a sustained upward trend in the density and extent of the spider population could be detected. Failure of the *D. plantarius* population to sustain the increase seen in 1998 (see Smith 1998 and Appendix 1) makes it essential that the current monitoring scheme is continued in 2000 (see Section 3.5).

2. **Water level monitoring**: Regular measurement of water levels in the spider pools should be continued throughout the hydrological recovery period. It is essential that this is extended in 2000 to include the new pools on Great Fen to assess their suitability for introduction of *D. plantarius* in 2001.

2.4.2 Management

1. **Modification of sedge -cutting rotation**: the band of *C. mariscus* cut in error on Middle Fen in 1999 should be left uncut when the remainder of the block of which it is part is cut in 2000 (Smith 1998). *C. mariscus* is weakened by cutting on too short a rotation.

2. **Removal of cut *C. mariscus***: a less destructive method of removing cut sedge must be found to avoid the severe compaction damage which resulted from using heavy tracked vehicles for this task in 1999.

3. **Integrity of grazing exclosures**: more care should be taken to maintain the integrity of the Middle Fen grazing exclusion area, which includes the core of the spiders'

range. Currently this area has no gate and so, in 1999, the fence was taken down to allow access for cutting and removal of sedge. Subsequent failure to repair the fence after the sedge was cut allowed access to the cattle from mid-August until October.

4. **Levelling of a sub-set of the spider pool depth gauges**, on Little, Middle and Great Fens, as part of the proposed levelling survey is still required. This will enable the surface water measurements to be related to the piezometer measurements, rather than to an arbitrary datum as at present.

5. **Marking new pools**: The pools dug on Great Fen in 1998 still need numbered oak marker posts to be installed in preparation for monitoring water levels (see 2.4.1-2 above) and the eventual introduction of spiders.

3. Future monitoring methods

3.1 Rationale for a new scheme

The prospect of a substantial recovery in numbers and expansion in range of *D. plantarius*, following closure of the bore-hole, presents new possibilities for monitoring. Finding a replacement for the current scheme is also necessitated by three factors. First, the prospect of significantly elevated water levels presents increasing health and safety risks. Second, there is also some evidence that at high water levels the spider population index is biased by dispersal into the flooded areas between the census pools (Appendix 1, Section 3.6). Thirdly, to be sustainable in the medium to long term, a monitoring method that can eventually be carried out by volunteers is required.

3.2 Specifications

The ideal specifications for a successful monitoring scheme for Redgrave and Lopham Fen were defined as follows:

1. Needs to cover the existing census pools to allow comparison and crude cross-calibration with present method

2. Should also cover between-pool areas since spiders are likely to become less pool dependent as the sedge beds become wetter

3. Should allow for much more substantial expansion in range than the present method so that progress towards the SAP range target can be measured

4. Should be possible for a volunteer to complete a full census round in a day and ideally repeat the work at not-more-than fortnightly intervals during the season

5. Should not entail health and safety risks beyond those associated with working outdoors and in the proximity of deep water

6. The data should be robust and analysable. Because absolute measures of population size are impracticable, the method must depend on standardisation of the observations. The use of volunteers in itself introduces the potential for much greater

variation in recording efficiency than has previously been the case. It is therefore vital the pilot work includes assessment of potential biases and seeks means of minimising these.

3.3 Pilot nursery web monitoring scheme

3.3.1 Introduction

Monitoring of nursery webs could potentially meet these specifications. Webs can be observed from the banks of the pools, posing little risk to safety, and can be counted much more quickly, under a greater range of weather conditions and with less expertise than the spiders themselves.

Counting webs along transects including both pools and between-pool sections gives the potential not only to monitor a large area relatively quickly but also to use distance transect methodology. By estimating the perpendicular distance from the transect line to the web, either precisely or by classifying in two or more distance belts, this method can be used to estimate densities. The potential therefore exists to quantify web numbers on an absolute rather than a relative scale.

However, nursery web numbers inevitably provide a much less sensitive measure of population size than counts of individual spiders. Their use as an indicator of population size could not be entertained until significant and sustained population expansion became likely: over the past nine years the use of webs as a population indicator has not been feasible because their numbers have been too low (e.g. zero in 1991, despite weekly monitoring). Nursery webs are used successfully as the indicator of population size on the Pevensey Levels, the second UK site for *D. plantarius*. However, the population there is much larger and location of the webs is much easier than at Redgrave and Lopham Fen (Jones 1992): the spiders are confined to linear ditches which can easily be viewed from the adjacent pasture land. Many of webs are located away from the banks, in floating vegetation such as *Stratiotes aloides*.

3.3.2 Objectives

1. Establish a method of counting webs at individual pools (count from one point vs walk round whole circumference. Look at observer biases resulting from (1) ability to spot webs, (2) height (affecting area which can be observed). Finalise a protocol for observations at individual pools.

2. Assess the feasibility and benefits of including counts along transects which include flooded sedge beds away from pools and areas further away from the current core populations than are covered by the present method (it may be possible to incorporate the walk between pools into the transect). Assess optimal width of transect to maximise number of observations but minimise observer bias.

3. Assess the optimal frequency of visits. Whilst numbers are relatively low the aim must be both to acquire as large a data-set as possible and to examine variation in breeding effort during the season. This can only be achieved by recording as many as possible of the webs built in the census areas during the breeding season (June to

September). Recording too frequently may restrict the attractiveness of the work to volunteers. The extent to which web numbers are under recorded by visits at weekly, fortnightly, three-weekly and monthly intervals should be assessed using weekly observation during the peak month for web-building (usually late July-early August). This problem can also be addressed by collecting daily data on the longevity of webs (this may be a suitable job for a volunteer). During the remainder of the pilot season I propose that data should be collected fortnightly, which is my current 'best-guess' at an appropriate time interval.

4. Devise a method of recording that ensures that newly-built webs are identified at each census so that a cumulative seasonal total is obtained (i.e. need a mapping method of recording).

5. Seek statistical advice where appropriate on data analysis

6. Write software for data entry and analysis

3.3.3 Progress towards objectives in 1999

Field Methods

Transect routes were established throughout the areas of Little and Middle Fen which could potentially support *D. plantarius*. These were subject to spring and early summer flooding and which have pools deep enough to hold water during favourable summers. The transects were walked once a week from mid-June to mid-August and then fortnightly until the end of September. I searched for webs by viewing from the transect line, using binoculars (high quality 10x32 optics, mimimum focus distance 2m) where practicable. Where the line passed pools, I standardised the point/s from which these were viewed. It proved impractical to walk right round the pools because it caused unacceptable damage to the tall, flooded vegetation and potentially to nursery webs amongst it. The locations of all webs seen were recorded.

All active webs were visited on a daily basis when possible and the web's height and supporting vegetation, the presence and size of the brood, presence of the mother and integrity of the web recorded. To help to define the date on which the web was built, dates when females with egg sacs had been observed at the web site prior to the appearance of the web were also recorded. Once the web was abandoned, its integrity, and consequent conspicuousness, was recorded on subsequent transect dates, or more frequently, until it was considered that it would be impossible to spot it without prior knowledge of its presence.

Results

A total of 33 webs was found along the transects during the 1999 season, nine of which were on Little Fen and 24 on Middle Fen. All of the webs were in marginal emergent vegetation around established pools: none was found amongst flooded vegetation away from the pools.

Of 103 nursery webs recorded in 1999 and in previous years, 74% were built in *Cladium mariscus*, 21.4% in mixed tall fen vegetation including *Cladium mariscus,* 2% in *Juncus* species and less than 1% in both *Carex elata* and *Phragmites australis*. The height of the webs varied between 0.1 and 1 m with a mean of 0.52 m (SE $\pm$ 0.02 m, n=99).

The young remained in the web for between 5 and 9 days before dispersing: precise estimates are difficult to obtain because the date on which a web is constructed is rarely known. This estimate is based on webs for which sequential records were collected in 1999 and in other years.

There was considerable variation in the period of time over which webs were sufficiently intact to be spotted. The longevity of the webs appeared to be more closely related to their position on the vegetation than to the length of time for which they were occupied by the brood: webs which were both high in the vegetation and amongst very pliable sections of leaves were torn in the wind more rapidly that those lower down and amongst stiffer stems. Most webs lasted considerably longer than the period in which they were occupied by young. The mean minimum life-expectancy of webs first spotted when occupied, based on the time from the date of first observation to the last date on which they were recorded as sufficiently intact to be likely to be detected, was 13.3 (n=17) days. The range was wide, from a minimum of four to a maximum of 31 days.

3.3.4 Developments and modifications required for 2000

Transects

On Middle Fen all of the transect routes followed existing bunds or barrow-ways and were relatively easy to relocate and access. Within the area used for the current annual census scheme on Little Fen, however, they followed paths cut for access to the pools. During the summer, it became clear that these routes are unlikely to be feasible in the medium term because of the depth of standing water along them and the difficultly of re-location if they are left uncut. New routes along barrow ways need to be sought in this area during the winter when the vegetation dies down. Because no webs were found away from the pools in 1999, such re-location of the inter-pool transect sections has no implications for comparability of the results.

Mapping of the transects was not possible during the 1999 season because the scheduled aerial photographing of the area was delayed until late summer. A map of the fen, drawn from the aerial cover, has been prepared for the 2000 field season but accurate location of some of the pools and routes is likely to require the use of a sensitive GPS.

When definition of all routes is complete, a system for permanent marking of the transect sections is required. Accurate measurement of the sections, which may be possible using a GPS, will be required in future if sufficient data become available to calculate web densities along the transects (Section 3.3.1).

Census methods

The considerable variation in longevity of the webs, with a mean minimum of 13 days, suggests that a significant proportion of webs would be missed with a fortnightly inter-census interval. However, a more frequent interval may be an unacceptable commitment for most volunteers.

A major problem with the development of the pilot scheme in 1999 was that, even with census work at weekly intervals, the numbers of webs found was too small to be an adequate basis for monitoring an endangered population. Moreover, the numbers of webs seen would almost certainly have been lower had I not had prior expectation of finding webs in locations where I had previously seen females (during monitoring from the water) with egg sacs (10/33 cases). I would almost certainly have missed a further four of the webs had I not been using high-quality, close focus binoculars.

The further major problem with the method was that visibility from the transect route, including viewing of most pools, is extremely restricted. As well contributing to low counts, the extreme spatial and temporal variation in the visibility is likely to bias substantially the ability to detect webs. Viewing of many pools, for example, is now highly restricted by an emergent fringe of *Phragmites australis*. Obtaining good access points for viewing many pools in also becoming increasingly difficult as water levels rise: small difference in the viewing point can result in large differences in the part of proportion of the pool viewed. Away from the pools, the height of the sedge and reed-dominated vegetation makes the viewing distance increasing short as the season progresses. In grassier areas, lodging of the vegetation following heavy rain can suddenly alter considerably the viewing distance. Management of the vegetation, most radically by mowing but also by grazing, also results in dramatic alteration in viewing distance both within and between seasons. All of these problems result in substantial and unpredictable variability in ability to detect webs. The considerable bias that this places on web counts is very difficult to quantify. Some sort of quantification of viewing distance is required but because of the fine spatial and temporal scale at which this is needed it is difficult to devise any method for achieving this, let alone one that could be managed by volunteers.

3.4 Alternative option for a new methodology

The problems encountered in developing a monitoring scheme based on counting nursery webs were considerable. A substantial increase in the numbers of webs is required before these can be more fully evaluated. Whilst it is hoped that this will occur in the 2000 season, it would be prudent to consider alternative possibilities for future monitoring.

The most likely option is to use point count methodology to count spiders from defined points on the banks of a sample of pools. Such counts could potentially incorporate information on numbers and size (on a three point scale) of individuals, stage of breeding cycle of adult females and presence of nursery webs. It may subsequently be necessary to reduce the data to presence/absence but, initially at least, the information content should be maximised. Numbers of records are likely to be substantially higher than for webs alone and this, together with the smaller time-commitment, are likely to make this method more rewarding for volunteers. The time needed at each pool will require prior evaluation but is likely to be in the order of 20 minutes. Because the area and number of pools that must be covered is large, I propose that this method is tested with as many volunteers as possible during a one ot two weekends in June/July. Observers' ability to locate spiders could be evaluated initially and each pool should be counted by more than one 'reliable' volunteer. Because of the problems of the very restricted view of some pools, the data on numbers of spiders seen would have to be expressed per unit visible bank length. Ability to estimate bank length within acceptable limits would need to be assessed by accurate measurement on the first occassion. One or two days counting of this kind at the peak of the season would overcome the problems of changing visibility within seasons. Estimation of the length of bank viewed gives the potential to correct bias resulting from the substantial between-year changes at some pools which could result from sedge-cutting.

3.5 Prospects and time-scales for changing the monitoring methods

Both the nursery web transect census and the point counts of spiders at pools would yield very substantially fewer and less informative data than the current methodology. Until a sustained and substantial increase in population size can be demonstrated on both Little and Middle Fen by the present methods, it is highly unlikely that either proposed method would be adequate to detect significant changes in population size or to evaluate progress towards the SAP targets. This means that the current methodology must be retained at least until 2001. The new methodology must also be in place that year with a view to changing over, if the recovery is sufficient, in 2002.

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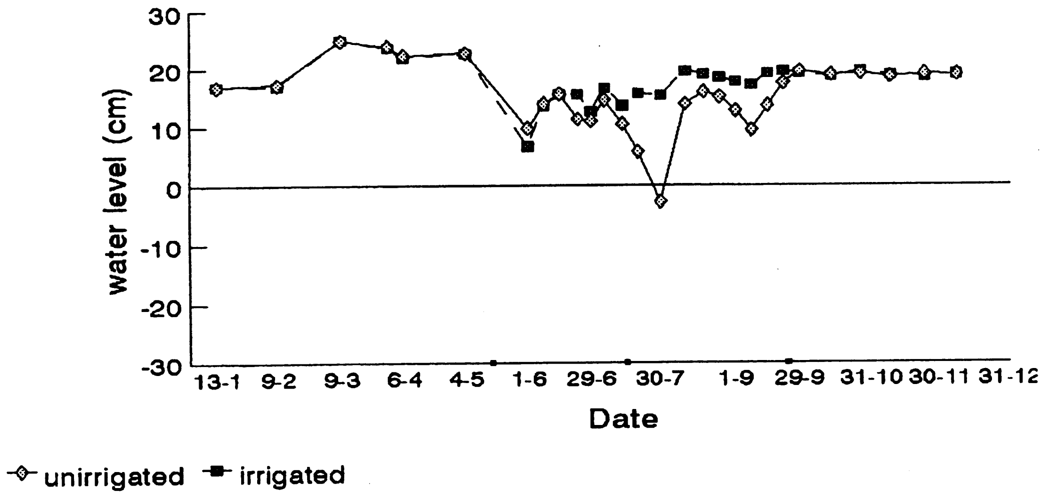
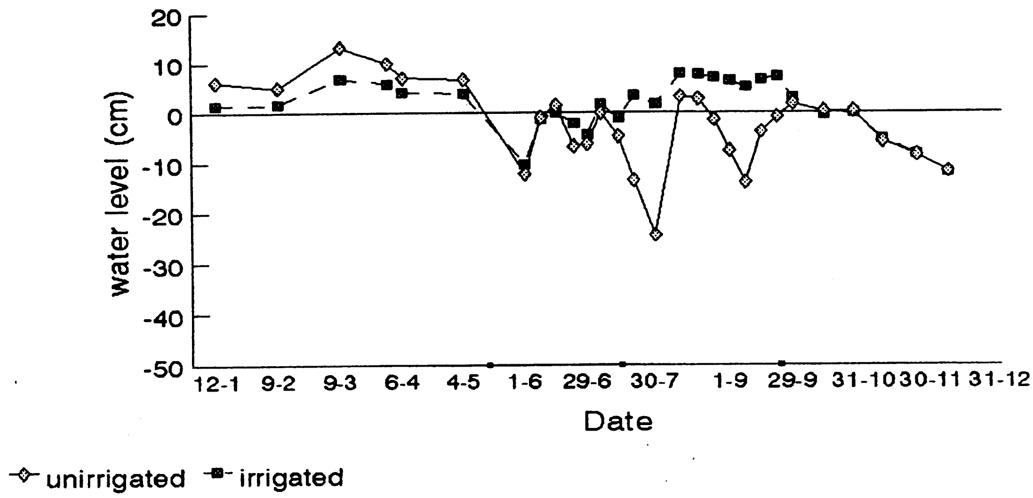
Figures

Figure 1. Mean water levels in pools censused in 1999

a) Little Fen



b) Middle Fen



Horizontal lines represent April 1992 datum

Vertical arrows show (1) start of irrigation, (2) increase in supply
and (3) end of supply

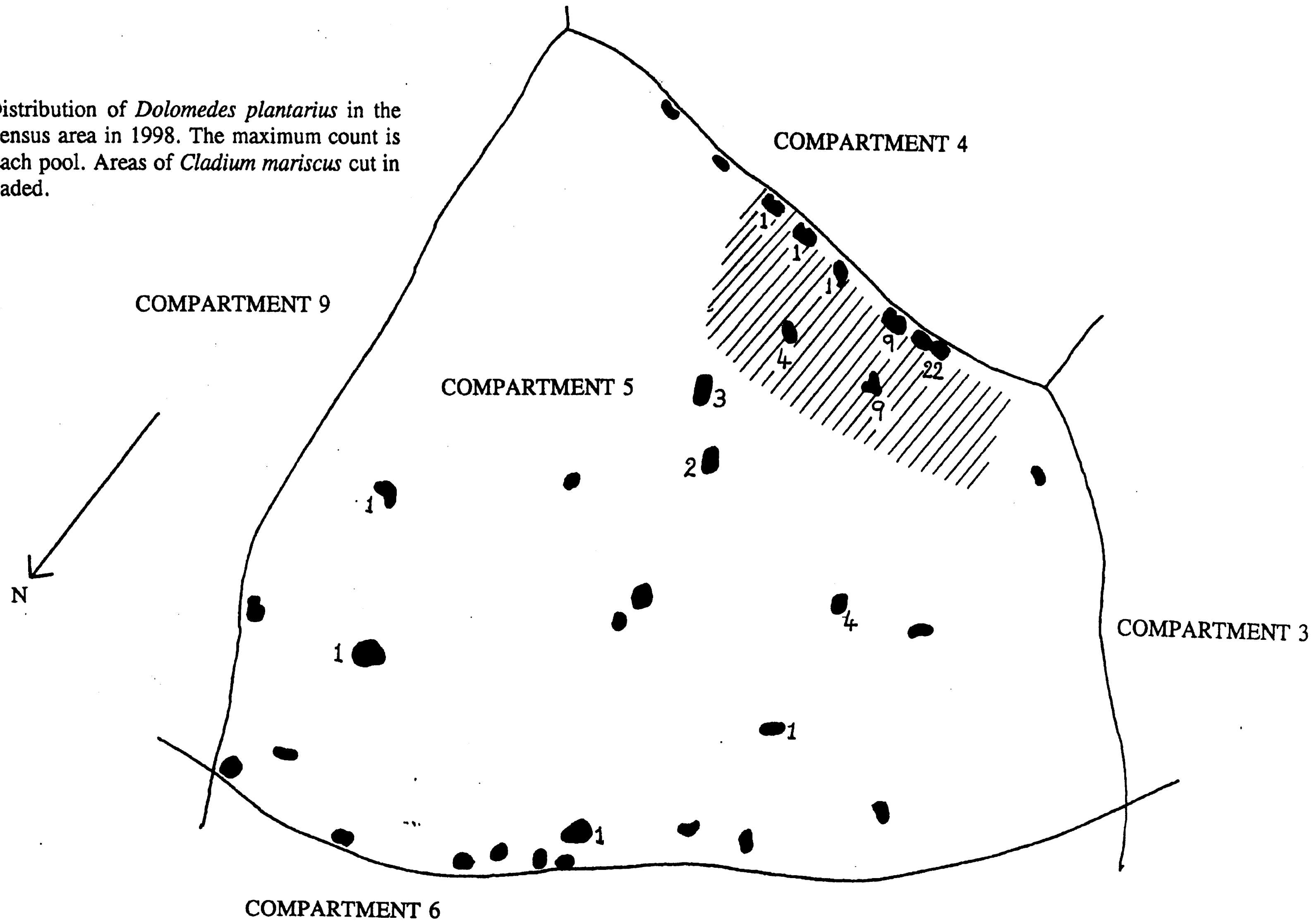


Figure 2 Distribution of *Dolomedes plantarius* in the Little Fen census area in 1998. The maximum count is shown for each pool. Areas of *Cladium mariscus* cut in 1999 are shaded.

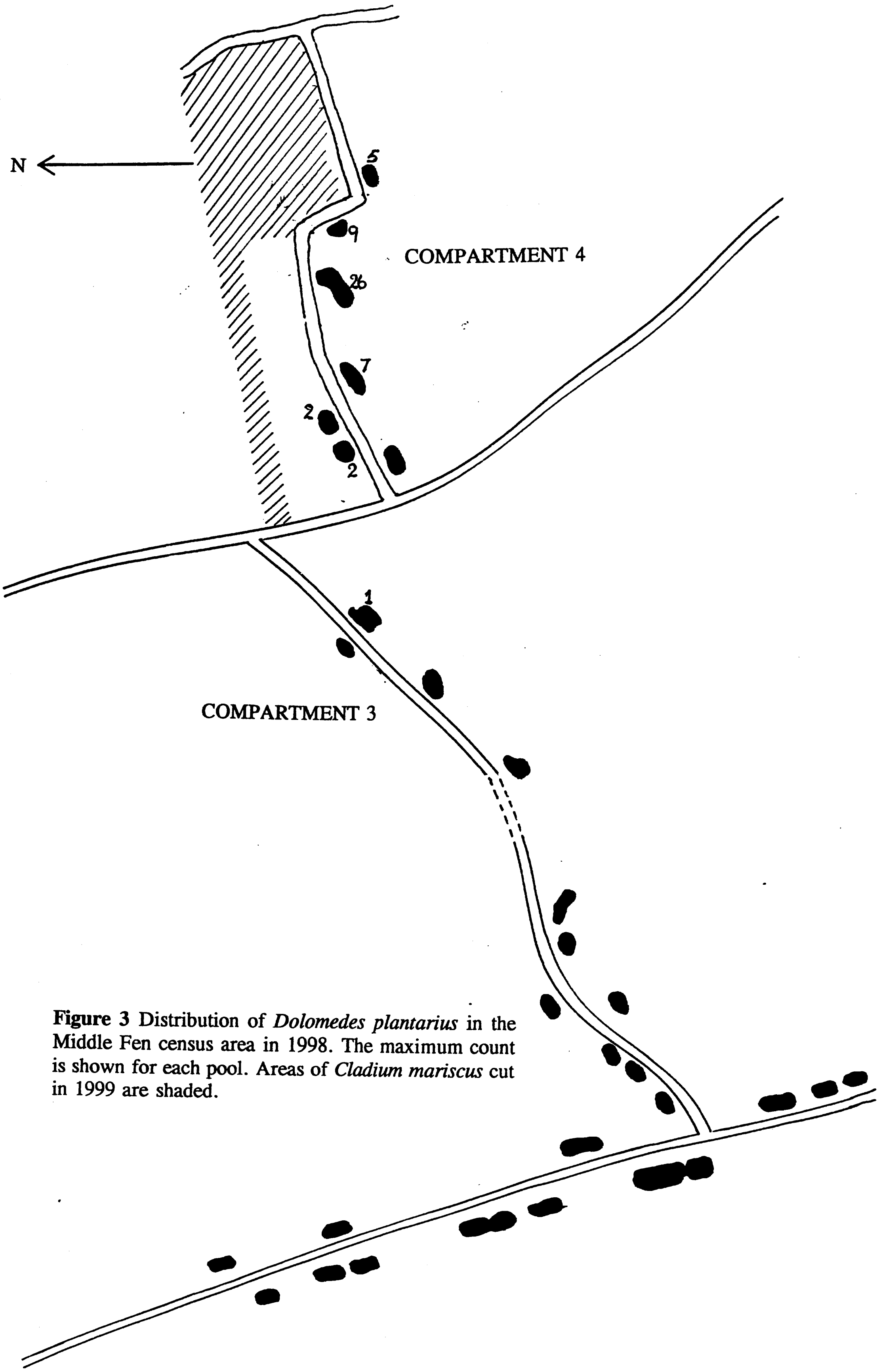


Figure 3 Distribution of *Dolomedes plantarius* in the Middle Fen census area in 1998. The maximum count is shown for each pool. Areas of *Cladium mariscus* cut in 1999 are shaded.

Part 2: Report for 2000

1. Introduction

This report describes the results of monitoring and management work completed as part of the Fen Raft Spider (*Dolomedes plantarius*) Recovery Project at Redgrave and Lopham Fen NNR in 2000. This was the tenth year in which a systematic census of the spider population was carried out: the background to the project and details of previous years work are given by Duffey (1991) and Smith (1992, 1993, 1994, 1995, 1996, 1997, 1998, 2000).

The report covers (i) the standard monitoring of spiders and of water levels, (ii) progress towards the development of a new monitoring methodology suitable for volunteers (iii) the management of vegetation and (iv) recommendations for monitoring and management in 2001. The rationale and specifications for a new monitoring methodology are given by Smith (2000).

2000 was the first full season during which there was no water abstraction from the aquifer underlying the fen, following closure last July of the artesian bore-hole which had drained the fen since 1960. The objectives for this new phase of the recovery project are, as defined in the *D. plantarius* Species Action Plan (U.K. Biodiversity Steering Group 1999), a ten fold increase in the range of the population and an increase in density to an average of *c.* 15 spiders per pool, the maximum recorded since systematic monitoring was started in 1991. Progress towards these objectives in 2000 is discussed in this report.

The monitoring work was financially supported by English Nature, with help from the Suffolk Wildlife Trust, as a contribution to the Species Recovery Programme.

2. Methods

2.1 *Dolomedes plantarius* census

The annual census of *D. plantarius* on Middle Fen followed the methodology used since 1993 and described by Smith (1993, 2000). The three replicate counts were carried out between 17 and 20 July. High water levels on Little Fen prevented census work in July because of the difficulty both of access and of interpreting results when areas between the pools are flooded (Smith 2000). Water levels did not fall sufficiently until early September, when a short period of suitable weather (11-14 September) allowed two census rounds to be completed before water levels rose sharply again after heavy rain. Autumn census work, using the standard methodology but only two replicate census rounds, was also carried out in 1993 and 1994, making possible direct comparison with the 2000 data.

2.2. *Dolomedes plantarius*: nursery web monitoring

The same methodology and transect routes were followed as in 1999 (Smith 1999). The transects were walked in early May and late June, weekly through July to mid-August, and then fortnightly into September. The data on web numbers are presented with those from the standard census in Section 3.2. An assessment of the feasibility of the method as a future monitoring tool is discussed in Section 6.1.3.

2.3 *Dolomedes plantarius*: point count census

An alternative to the nursery web census method, using point counts of spiders, was piloted on 6 August in 2000, using 15 volunteers most of whom either had experience of using point count methods in the field, or were very familiar with *D. plantarius*. On Little Fen timed point counts were made at all but one (L29) of the Little Fen pools used in the standard annual census. Two 15 minute counts were made by different observers at each of 25 pools. Four further pools were counted only once. On Middle Fen counts were made at those annually censused pools which were within the range of *D. plantarius* established at the July census (10 pools). Fifteen minute counts were made at each pool by between five and seven observers.

The counts were made from pre-defined points on the banks of each pool, marked by canes. Observers were asked to count only from this point and not to try to increase their field of view by moving. Most observers used binoculars (the focal distance of which was measured) and recorded whether each spider was first seen with binoculars or with the naked eye. The start time for each count, and the time at which each subsequent sighting was made, was recorded. Estimates of the size of the spiders (as small, medium and large) were made and individual features, including whether or not they were banded and, for adult females, stage of the breeding cycle, were recorded. At the end of the 15 minute count, observers were asked to recorder how many of the spiders spotted were still visible. To avoid biasing individual results, observers were asked not to communicate their results to other members of the team.

2.4 Water levels

Water levels were measured in all of the census pools at fortnightly intervals. From April onwards they were also measured at fortnightly intervals in five of the pools dug on Great Fen in 1998 (Smith 1998), which are being assessed for their suitability for reintroduction of *D. plantarius*.

3. Results

3.1 *Dolomedes plantarius*: abundance and distribution

3.1.1 Little Fen

On Little Fen *D. plantarius* was found scattered throughout much of the census area in September (Fig. 1) but only 11 pools were occupied cf. 15 in July 1999 and 20 at the population's peak in 1998 (Table 1).

No annual population index was calculated for Little Fen because direct comparison of the September records with those from July in previous years (Smith 1993-1998) may be misleading. However, numbers recorded during the September census were low compared with those in July 1999 and were very similar to those found on Little Fen when September records were last collected, in 1993 and 1994 (Table 2). The size distribution of spiders was very similar to that in 1993, with a low proportion of small spiders in the population compared with 1994 (Table 2), as well as in comparison with July in most other years (Tables 2 & 3). Only one adult female was recorded, again the lowest number since 1993 and 1994 (Table 2 & 3).

3.1.2 Middle Fen

On Middle Fen *D. plantarius* was recorded in all of the formerly irrigated pools (Table 1) and, for the second consecutive year since its disappearance after 1994, in pools to the west of the formerly irrigated area (Fig. 2). The area occupied extended slightly further west than in 1999 although there was no extension beyond the range occupied during the last decade.

The annual population index, derived from a log-linear Poisson regression model (Smith 1995, 2000) of the ten-year run of systematic census data for Middle Fen, was the highest so-far recorded (Fig. 3). However, the increase on previous years was small and the index value was not significantly greater than those for the previous two years. As in previous years, the model that best described the data (lowest AIC[1] value) was the time effects model (separate effects for each year). This model had an AIC value of 16.86, while the linear trend model and no time effects model had AIC values of 191.6 and 285.6 respectively.

The maximum number of spiders counted on Middle Fen was the highest, and the mean number recorded per occupied pool the third highest, of the eight years for which comparable data are available (Table 3 and Fig.4). Although numbers of adult females were similar to those in many recent years, they comprised a smaller proportion of the total. A similar proportion of the population was in the medium size class and greater proportion in the small class than in 1999. However, none of the spiders recorded as 'small' were of a size likely have represented the new 2000 cohort but were small individuals from the 1999 cohort (see below).

3.2 *Dolomedes plantarius*: breeding season

The 2000 breeding season was poor. On Middle Fen, no nursery webs were encountered during the July census and only two during the nursery webs transects throughout the season. This contrasted with 1999, when seven nursery webs were recorded during the July census, and a total of 24 during the nursery web transects throughout the season. The picture was similar on Little Fen. No webs were found either during the census or the web counts whereas four and nine webs respectively were recorded in 1999 (three webs were found during sedge cutting in 2000).

There was also evidence that the 2000 breeding season started later than usual. Three females with egg sacs were seen on Little Fen on 28 June but their webs were not found (below) despite subsequent searching. All but one of the adult females seen during the census round between 17 and 20 July were carrying eggs or were pregnant. All of the females seen at this time in 1999 had nursery webs (Table 3). The first sighting of a nursery web in 2000 was during sedge cutting on 27 July and the first recorded on the nursery web transects was on 13 August: the first sighting in 1999 was on 30 June and the earliest date on which webs have been recorded from this site is 7 June.

3.3 Point count census

3.3.1 Estimation of population size

On Little Fen, despite the extensive coverage within the spider's range, only one definite and two possible sightings of *D. plantarius* were made. The weather on the day of the count was warm and sunny and conditions were ideal for seeing spiders basking.

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[1]Akaike information criterion (Akaike 1973, Burnham & Anderson 1992)

On Middle Fen, numerous spiders were in evidence (Table 4). They were recorded from all pools on which they were seen at the July census (although not by all observers). On most pools the maximum count obtained by this method was lower, and often substantially lower, than by the current census method (Table 4).

3.3.2 Differences between observers

Because different observers counted different sets of pools, observer performance is expressed as the mean percentage of the maximum count from each pool scored by each observer (Table 5). One observer was much more experienced than the others and obtained contributed almost all of the maximum counts. This observer's performance score was significantly higher than those obtained by most other observers.

The observer responsible for the second highest score was inexperienced in point-count field techniques and tended to increase his field of view substantially by moving from the pre-defined counting positions. It will be important in future years to re-inforce the importance of this discipline, both to retain comparability between observers and to avoid damage to the pool margins.

The differences between the remainder of the observers were relatively small and non-significant. This suggests that, particularly in the absence of an observer very experienced in spotting this species, a team of good field workers may be able to produce consistent results.

Multiple counts should be continued at each pool at least during the development phase of the scheme so that the extent and causes of variation between observers can continue to be evaluated.

3.3.3 Estimation of size categories

Estimating size categories without prior experience of the size range and with observers using combinations of the naked eye and binoculars of differing quality, proved extremely difficult. Observer reports at the time, and subsequent inspection of the data, suggests that there were substantial differences between observers in perception of size. Although it seems unlikely that useful size data will be obtainable by this method size records should be kept for at least one more year to anable proper analysis of the extent of observer bias. It may, however, be possible to collect more reliable data on the presence of breeding females and of very small juveniles.

3.3.4 Duration of counts

Analysis by time intervals of the fifteen minute count chosen for this pilot study shows that the highest proportion of spiders was spotted very early in the count and that numbers dimished from then onwards (Fig. 5). Five percent of spiders were first seen during the last three minutes of the count.

On Little Fen, some observers commented that, in the absence of spiders, the 15 minute observation period was too long for them to retain their concentration. On Middle Fen, where spiders were abundant, observers did not complain about the length of the count: the possibility of continuing to make new observations throughout the period retained their interest. In future a slightly shorter time (possibly 12 minutes) may be selected as a compromise between this problem and the potential loss of data. Using different durations of count on the two fens and in different years, according to the perceived population size, is not an option because because of the need to retain comparability of data.

The sample size was inadequate to assess the influence of using binoculars on the totals counted. This may become possible as data accumulate in the future but there are many confounding influences. These include differing focal lengths and optical quality of the binoculars used and the experience and strategy (using binoculars from the outset or as a secondary aid) of the observers. The potential impact of binoculars on numbers counted may be better addressed by a specifically designed trial. Although it may be impractical to define 'rules' for counting with binoculars, is nevertheless desireable for the development of the method, to know whether, on average, they result in a significant increase in numbers seen.

3.4 Water levels

2000 was the first year since 1991 when artificial irrigation of the core spider pools on Little and Middle Fens was not needed to maintain adequate water levels throughout the summer. Data for formerly irrigated and unirrigated pools have nevertheless been plotted separately to allow comparison with previous years' data (Figs. 6 and 7).

3.4.1 Little Fen

High winter rainfall led to exceptionally high winter and spring water levels on Little Fen (Fig. 6 (b)). These levels were sustained throughout the spring and augmented by exceptional rainfall in early June. A very gradual fall during July and August was reversed by mid-September. The lowest mean levels reached were still *ca* 16 cm higher than the lowest point in unirrigated pools in 1999, which was itself one of the wettest summers of the decade. Levels in the formerly irrigated pools were *ca* 10 cm lower, at their lowest point, than when they received an irrigation supply in 1999 (Fig. 6).

3.4.2 Middle Fen

As in 1999, winter water levels were high but, by May, a clear contrast had developed between the two years (Fig. 7). In 1999 levels began to fall in early May but in 2000 they were sustained until mid-August. The fall in late August lasted only until mid-September and the low point was 9.5 cm higher than that in the wet summer of 1999. The low point reached in the drought of July 1996, was *ca* 80cm lower than in 2000 (Smith 1996).

The slightly lower water levels in the formerly irrigated pools than in the unirrigated pools throughout the season reflects a gradient in the surface water levels from east to west across Middle Fen. This gradient is accentuated when water levels are high (see Fig. 7). The low point reached in the formerly irrigated pools was *ca* 18 cm lower than when they were irrigated last year but this fall was both relatively late in the season and short-lived.

3.4.3 Great Fen

Water levels in the pools excavated on Great Fen in 1998 responded to the high rainfall in May and June before dropping progressively as the level fell in the Great Fen section of the Waveney (expressed relative to OD: Fig. 8). Recovery after mid-September was rapid.

4. Vegetation management

4.1 Rotational cutting of *Cladium mariscus*

On Little Fen two blocks of *C. mariscus* were cut in 2000. The easterly block (shown on Fig. 1) formed part of the rotation agreed in 1998 (Smith 1998). It was cut in the last week of July and cut material was removed over the following two weeks. The westerly block formed part of the area originally scheduled for management by grazing in 1999. It became clear in 1999 that the animals were unlikely to make any significant impact in this area. It was therefore agreed that the size of the rotational cutting area should be expanded for a further cycle. This area was cut in the second week of August but removal of cut material was not completed until the end of the month.

On Middle Fen the block of sedge shown in Fig. 2 was cut on 25 July and the cut material was removed on 30 July. The strip along the north side of this block, which was cut in error in 1999, was re-cut in 2000.

The very high summer water levels made vehicular access impracticable and removal of cut material difficult. On both Little and Middle Fens the cut sedge was removed by winching it over the flooded areas of the fen, across tracts cleared of vegetation by cutting. This resulted in very substantially less damage to the substrate than in 1999 (Smith 1999).

4.2 Grazing

Management by grazing of areas occupied by *D. plantarius* outside the exclosures was much more successful on Middle Fen than on Little Fen. Stocking rates were higher on Middle Fen and water levels were lower, giving the animals better access to all areas. Details of stock types, rates and movements, are given by Excell (2000). The Tarpan ponies used on Middle Fen reversed substantially the dramatic encroachment of *P. australis* in this area which had occurred over the past three years. By late August they had started to graze the *P. australis* that surrounds and shades many of the formerly unirrigated pools.

On Little Fen, however, the Sussex cattle made very few incursions into the areas occupied by spiders. Like the Tarpans used in 1999, they had a negligible effect on the vegetation in these areas.

4.3 Clearance of *Phragmites australis* from Middle Fen pools

Winter removal of mud and reed rhizomes from *ca* half of the machine-dug pools within the spiders range on Middle Fen, originally scheduled for the winter of 1998/'99, was not carried out. The agreed alternative, of croming pools in summer to control shading by emergent *P. australis*, was completed on only a very small number of Middle Fen pools. Some of the pools scheduled for management are now densely infilled by emergent vegetation.

5. Discussion

The dominant influence on the two *D. plantarius* sub-populations on Redgrave and Lopham Fen in 2000 was the presence of high water levels throughout the season for the first time since systematic monitoring began ten years ago. These water levels resulted from a combination of the effects of closure of the artesian bore-hole in July 1999 and levels of rainfall highly atypical of the last decade. The relative contribution of these two factors cannot be assessed with the data currently available.

As predicted (Smith 2000), maintenance of higher water levels on Middle Fen benefitted the spider population, sustaining it at the highest level recorded to-date, primarily by increasing survival rates of the relatively large 1999 cohort. However, neither the numbers recorded, nor the slight expansion in range, were significantly greater than in some previous years and, despite the higher water levels, the 2000 breeding season was poor.

Poor breeding success may have resulted from a combination of factors: the cold spring resulted in slow growth rates and a late start to the season, the numbers of adult females were no higher than in recent years and the numbers of nursery webs were much lower. Even during the peak of the breeding season very few webs were encountered. This scarcity could not be attributed solely to low numbers of adult females. In previous years was possible to find the webs made by the majority of females first seen as pregnant or with egg sacs. In 2000, nine females were seen with as pregnant or with egg sacs but their webs were not found despite frequent subsequent searching. On Middle Fen two sightings of postpartum females, in precisely the same positions previously occupied by females with egg sacs a few days earlier, increased the probability that some egg sacs were abandoned. This circumstantial evidence that females may have abandoned egg sacs, in combination with the discovery of several sacs with infertile eggs in 1999, may indicate that problems are occurring in the breeding system. Marking, to allow closer observation of individual adult females and, eventually, DNA analysis, are needed to gain an understanding of these problems. Thus, although the higher water levels appear to have improved survival on Middle Fen, the population failed either to expand substantially or to produce a new cohort of sufficient size to give the potential for rapid expansion in the near future.

In contrast to Middle Fen, there is strong evidence that the much higher water levels on Little Fen in 2000 were deleterious to the *D. plantarius* population. Although the high levels made a summer census impossible, the small numbers of sightings during casual observation of the pools during the spring, and the very small numbers seen during the point count census in early August, gave cause for concern. Although it was possible that a high proportion of the population was dispersed throughout the flooded sedge beds, the preference of this species for hunting and basking in open sunny conditions, and for hunting over an open water surface, made this relatively unlikely. However, if the population were to disperse in this way, the standard census methodology, based on counts made at pools, would be inappropriate (Smith 2000).

The results from the census carried out in September provided strong quantitative evidence for a substantial decline in the Little Fen population. At that stage, water levels on Little Fen were comparable with those in July 1999, when the numbers of spiders counted on the pools were high. The last time counts were made in both July and September, in 1993 and 1994, the autumn counts were higher than the summer counts suggesting that the autumn 2000 count may overestimate summer numbers. Furthermore, the numbers counted in September 2000 were very similar to those encountered in 1993 and 1994. The summer counts in both of these years were the lowest during the last decade and in both years Little Fen was flooded during the winter. It seems increasingly likely that protracted, deep flooding, particularly during the spider's hibernation period, can result in mortality. During the 1999/2000 winter, the majority of the bases of the *C. mariscus* tussocks, amongst which it is likely the *D. plantarius* hibernates, were submerged, leaving only the upper parts of leaves emerging from the water. The effects of flooding *per se* may be exacerbated by those of poor water quality but the data currently available make it impossible to evaluate the impact of water quality on the fen vegetation, let alone any direct effects it may have on the spiders.

The rapid loss to *P. australis* of the *C. mariscus* beds and of the *Calamagrostis*-dominated litter fields on Little Fen presents a further threat to the recovery of *D. plantarius*. Eutrophication and increased water depth are likely to be responsible for this change. Although grazing has had a substantial impact on similar changes in the vegetation on Middle Fen, it has been completely ineffective in preventing the spread of *P. australis* on Little Fen over the last two years. Even with higher stocking rates this situation is unlikely to improve unless water levels are reduced. The animals are discouraged by both the deep flooding of the areas occupied by spiders and the ready availability of more palatable food in more accessible parts of this large grazing compartment.

6. Recommendations for management and monitoring in 2001

6.1 Monitoring and research

6.1.1 Maintenance of current census method

The census scheme initiated in 1993 was intended to be maintained until a sustained upward trend in the density and extent of the spider population could be detected. The decline in the Little Fen population and failure of the Middle Fen population to expand significantly in 2000 makes the continuation of sensitive measurement by the current methodology critical for at least two further years. The pilot work on both the point-count and the nursery web transect methods show that they are insufficiently sensitive to detect significant changes in population size or to evaluate progress towards the SAP targets while the population remains small (below).

6.1.2 Annual point count census by volunteers

The pilot for a point-count census showed that, even using the same, experienced observer, maximum counts were on average 45% lower (pools with>2 records) than from the current annual census. Using less experienced observers, the discrepancy is greater and no reliable data can be collected on the age/size structure of the population. This method is therefore substantially less sensitive and informative than the current method.

In the event of a substantial population recovery, however, this method has potential for the long-term monitoring of *D. plantarius*. In the absence of a single very experienced observer, it was shown the use of replicate counts at pools could produce reasonablly consistent results. It should therefore be maintained as an annual event both to refine the methodology and to maximise overlap with the current data set. As the sample of counts grows, more rigorous analysis of the potential biases will become possible and both the field and analytical methods can be improved.

6.1.3 Nursery web transects

The very low numbers of webs found by this method over that last two years show that it is not viable as a monitoring method for this population unless there is a very substantial increase in population size. The numbers of records collected at this stage are too small to be used to develop the methodology and so there is little current benefit in continuing to pilot the method.

6.1.4 Marking adult females

Evidence suggesting that the population may be encountering breeding problems makes it more critical than ever that adult females are identified individually. Marking of females by previously-established techniques (Smith 1993) is required, together with frequent subsequent searching for marked individuals.

6.1.5 Effects of *P. australis* on *D. plantarius*

The apparent negative correlation between the extent of *P. australis* encroachment around the pools and the abundance of *D. plantarius* is an increasing cause for concern because of the spread of this species at the expense of *C. mariscus*. It is important that the extent of the spread of *P. australis* is properly quantified: the current vegetation monitoring scheme, using a grid of permanent quadrats, is inadequate to evaluate these changes.

Better data are also needed on the strength and causes of the apparent negative correlation between these two species. Limited data collected in 2000 suggests that shading significantly lowers pool water temperature. This may have direct and indirect effects on *D. plantarius*. There is already evidence, which needs more critical examination, that the structure of *P. australis* is unsuitable for breeding *D. plantarius*.

6.1.6 Water level monitoring

Regular measurement of water levels in the pools on Little and Middle Fens should be continued in 2001 although, during periods when the water table is high and the variance between the pools very low, the sample size could be reduced. Regular monitoring of the pools on Great Fen must also be maintained so that the effects of installation of the proposed Great Fen sluice, and consequent suitability for introduction of *D. plantarius*, can be assessed.

6.2 Management

6.2.1 Rotational cutting of *C. mariscus*

It was agreed in spring 2000 that part of the main sedge bed on Little Fen which lies outside the designated mowing area should be returned to the mowing cycle. As a result of this decision, the northern part of sedge Block 2 should be mown in addition to the scheduled Block 3 (see Smith 1998). Although it had originally been suggested that this area might be managed by more intensive grazing than the remainder of the compartment, the experience of the last two years has shown, not only that it is impracticable to increase the stocking density on this sort of terrain by fencing, but also that the stock do not elect to graze this area.

The practical problems of sedge cutting on the uneven terrain of Little Fen were exacerbated this year by the very high water levels in the sedge beds. Better ability to control water levels in wet summers is needed for this operation to be carried out in a safe and cost-efficient manner.

6.2 2 Control of water quantity and quality

The evidence in this report suggests strongly that very high water levels, resulting in permanent and deep flooding of the fen, are unfavourable to *D. plantarius*. It is very unlikely that such high water levels were the norm on Little Fen before the fen was drained because the extensive peat cutting and sedge harvesting activities would have been impossible. The water appears to have been impounded within this area either by lowering of the surface through peat degradation or because the bunds built across the valley during the restoration operations impede its flow. The sluice system is inadequate to control levels and maintain a flow of surface water across Little Fen for much of the year. This problem, together with the ongoing problem of polluted water entering the fen, must be addressed urgently to avoid further decline in this very precarious population.

6.2.3 Control of *P. australis* in the sedge beds and litter areas

2000 saw further development of tall, dense reed at the expense of both *C. mariscus* and *Calamagrostis*-dominated vegetation, continuing the significant decline in the amount of suitable habitat available to *D. plantarius* on Little Fen. In 2000, as in 1999, grazing stock did not enter these areas. Lower summer water levels may give the stock better access to this area but the height and density of reed in parts of the area are now such that stock are likely to be deterred from entering. Cutting of reed and allowing grazing of the regrowth in some areas may also be needed to control this problem.

6.2.4 Clearance of emergent *P. australis* from pools

The delays in clearing emergent vegetation (primarily *P. australis*) from the pools on Middle Fen have led to a situation where the pools are becoming densely infilled and progressively less suitable for *D. plantarius*.These pools require urgent attention to restore their suitability for *D. plantarius*.

6.2.5 Path maintenance

The paths within the grazing exclosures, along the bunds between the formerly irrigated pools on both Little and Middle Fen, were not maintained during 2000, resulting in extensive colonisation by *P. australis*. This resulted in further shading of the pools on either side as well as leading to difficulties of access for monitoring and rapid degradation of the rich path flora. A narrow track was cut along each of these bunds with a brush-cutter in August but the tall litter was left lying, leading to further damage to the flora. High water levels this year made mowing of these areas impracticable until August. When water levels permit, more regular mowing of these tracks is recommended. Maintenance of the paths between the census pools in the interior of Compartment 5 on Little Fen, normally carried out once or twice annually, continues to be required to facilitate access for monitoring.

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Table 1 Numbers of census pools on which *D. plantarius* was recorded in July each year. On Little Fen 'irrigated pools' include all those benefitting from irrigation water, either directly or indirectly. Note that irrigation water was not supplied in 2000: the figure in parentheses for Little Fen in 2000 applies to all pools at the September census.

Year:		1993	1994	1995	1996	1997	1998	1999	2000
Little Fen	Irrigated (n=16 pools)	8	8	12	9	12	14	11	(11)
	Unirrigated (n=15 pools)	2	2	4	0	1	6	4	
Middle Fen	Irrigated (n=7 pools)	6	7	7	5	6	7	6	7
	Unirrigated (n=23 pools)	2	3	0	0	0	0	1	2

Table. 2 Comparison of numbers and densities of spiders, and of numbers of pools occupied, on Little Fen in September 1993, 1994 and 2000. Means are maxima of two counts per pool, for occupied pools only (1SE in parentheses).

Year:	1993	1994	2000
% large spiders	28	18	26
%medium spiders	59	36	61
%small spiders	13	46	13
Max. spider count	31	33	31
Max. adult females	6	1	1
Nursery web count	1	0	0
Mean spiders/pool	2.58 (0.4)	2.75 (0.06)	2.75 (0.70)
No. occupied pools	11	12	11

Table 3. Proportions of *D. plantarius* in different size classes, and maximum counts of all individuals, adult females and nursery webs, in the Little and Middle Fen census pools in July 1993-2000

	1993	1994	1995	1996	1997	1998	1999	2000
Little Fen								
% Large	36	21	20	65	30	5	8	-
% Medium	57	37	66	15	41	50	53	-
% Small	7	42	15	20	29	45	39	-
Max. spider count	**14**	**19**	**41**	**20**	**66**	**94**	**62**	-
Max. adult females	0	1	6	6	16	4	4	-
Nursery web count	0	2	0	0	9	0	4	-
Middle Fen								
% Large	29	30	3	17	47	5	15	6
% Medium	33	48	62	34	53	32	46	49
% Small	38	22	35	49	0	63	39	45
Max. spider count	**21**	**44**	**102**	**41**	**15**	**99**	**52**	**112**
Max. adult females	0	8	1	5	6	5	7	7
Nursery web count	1	3	1	0	0	0	7	0

Table 4. Comparison of maximum counts on the Middle Fen pools at the July census and the volunteers point count census by volunteers on 6 August 2000

Pool number	Maximum count	
	Point count	July census
5a	5	12
7	2	17
10	12	26
15	11	22
16	11	12
18	9	17
19	6	10
22	4	5
22b	2	1
24	1	0
26	0	0

Table 5 Performance of observers during point counts, expressed as mean percentage of maximum count obtained at each pool by each individual

Observer	Mean % of max. recorded	2SEs
1	96.45	13.2
2	68.64	24.2
3	50.7	23.6
4	48.9	18.2
5	47.4	29.4
6	40.3	11.4

Figures

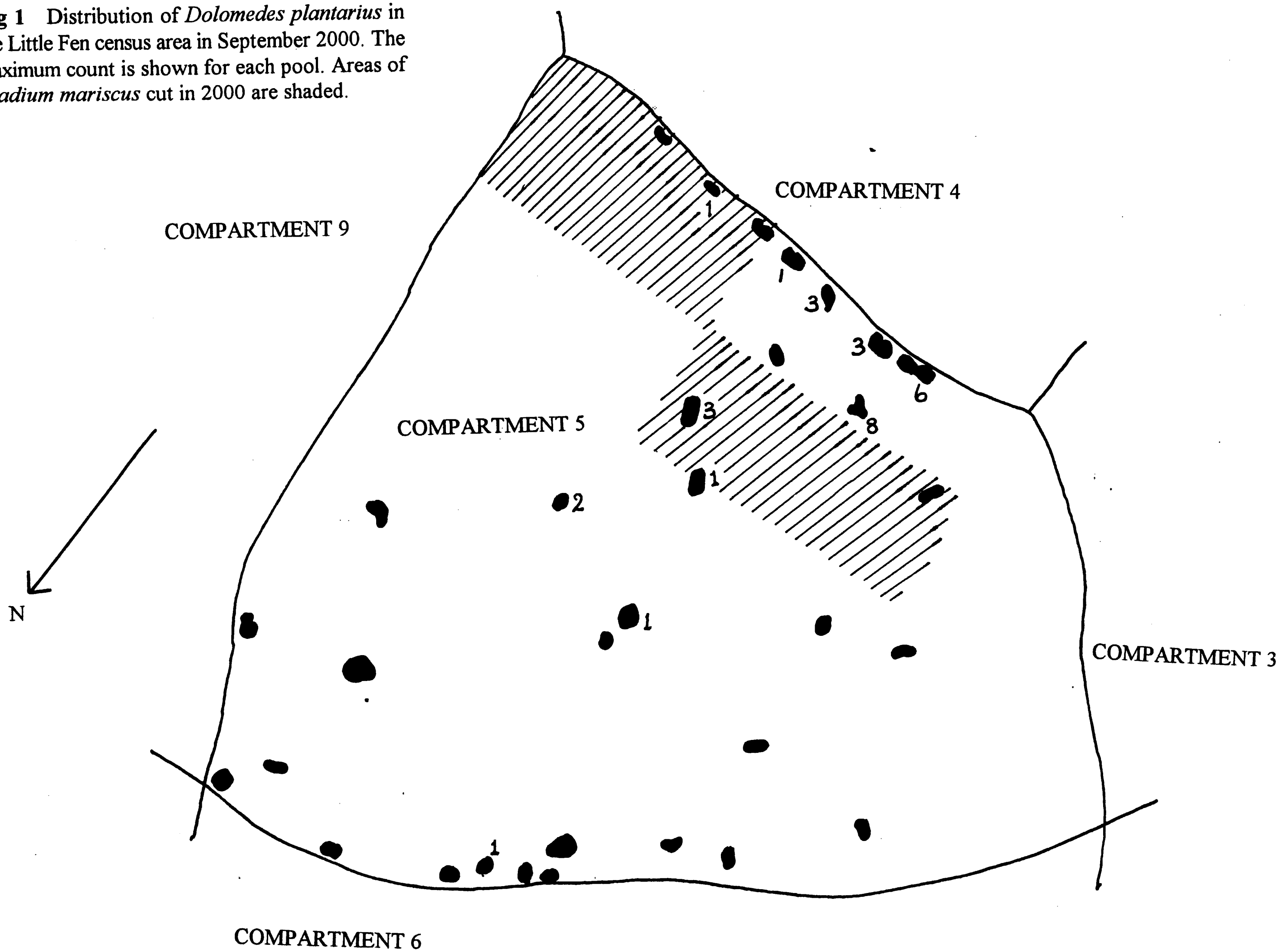


Fig 1 Distribution of *Dolomedes plantarius* in the Little Fen census area in September 2000. The maximum count is shown for each pool. Areas of *Cladium mariscus* cut in 2000 are shaded.

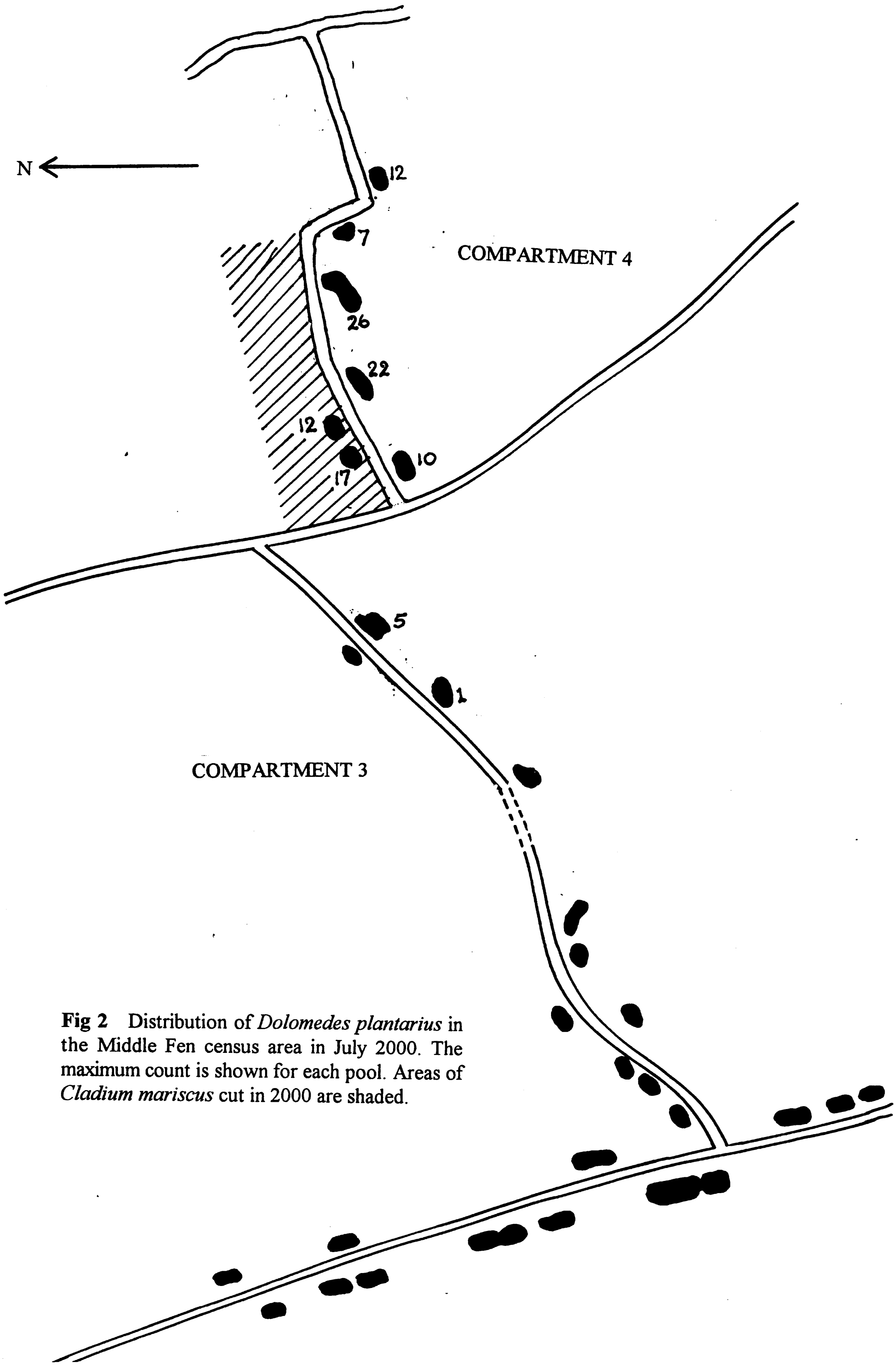


Fig 2 Distribution of *Dolomedes plantarius* in the Middle Fen census area in July 2000. The maximum count is shown for each pool. Areas of *Cladium mariscus* cut in 2000 are shaded.

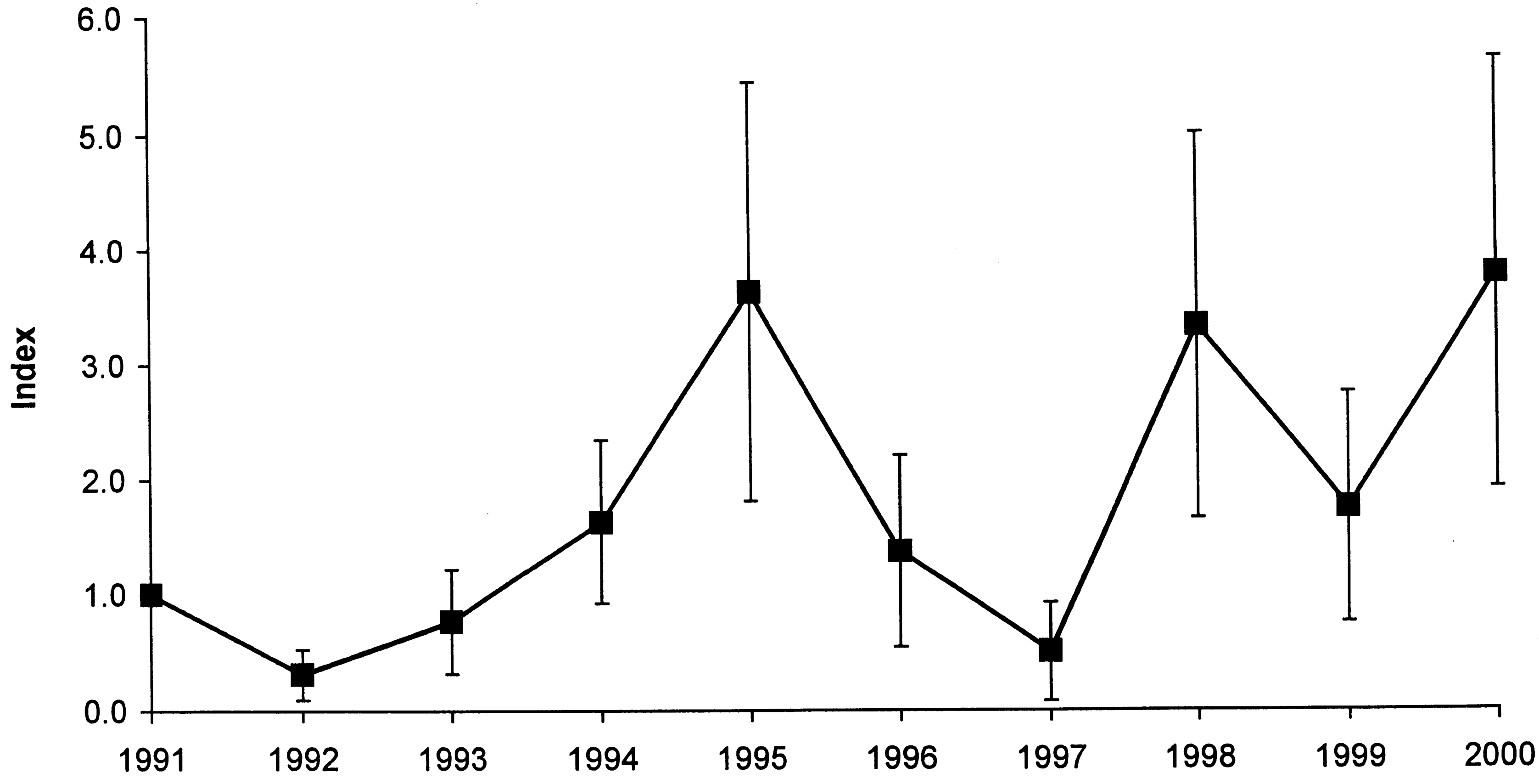


Fig. 3 Annual popuation index for *D. plantarius* on Middle Fen, generated by a log-linear Poisson regression model and plotted on a linear scale. Vertical bars denote 2SEs.

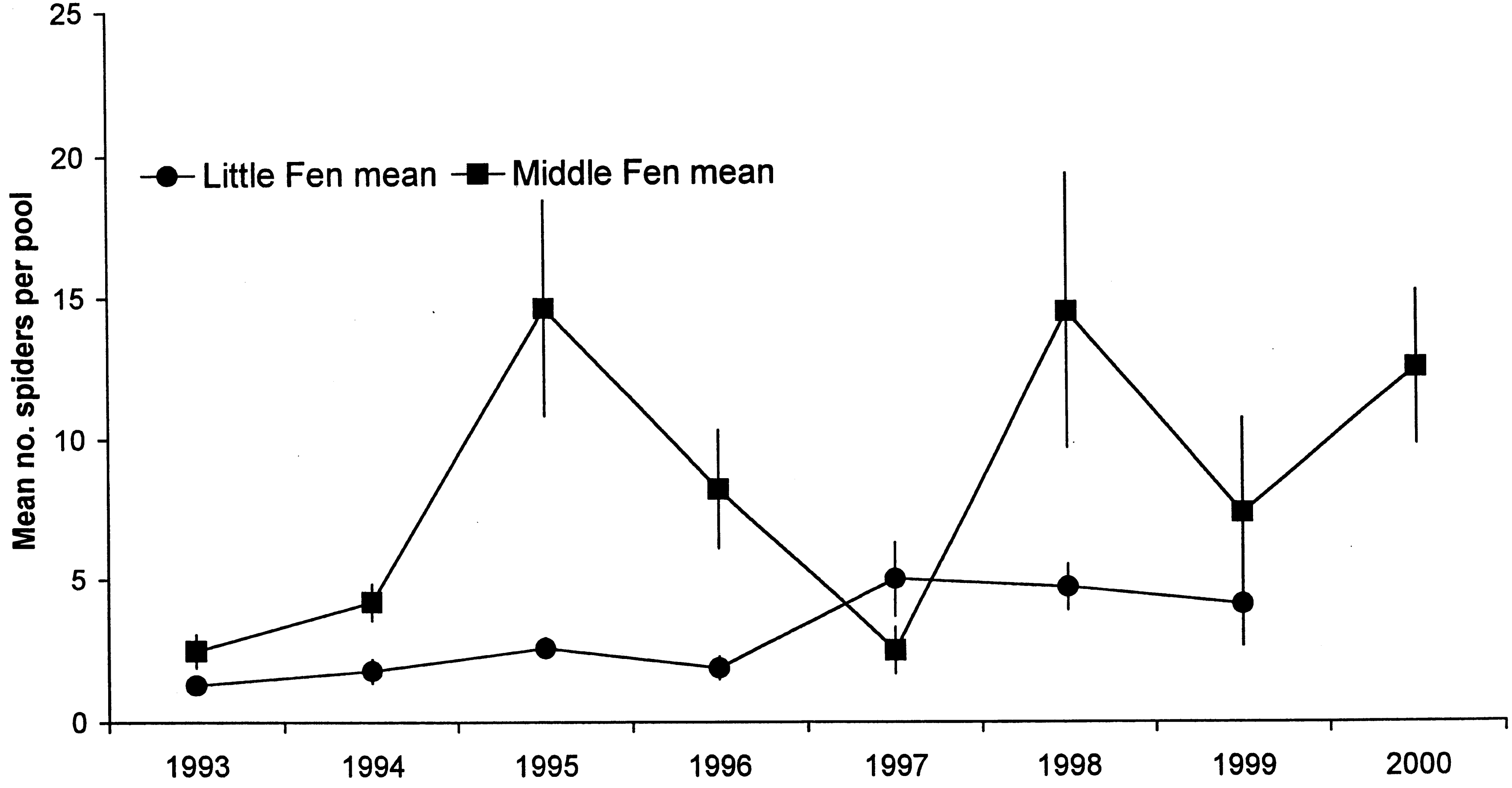


Fig. 4 Mean numbers of spiders per occupied pool on Little and Middle Fen. Vertical bars denote 1 SEm

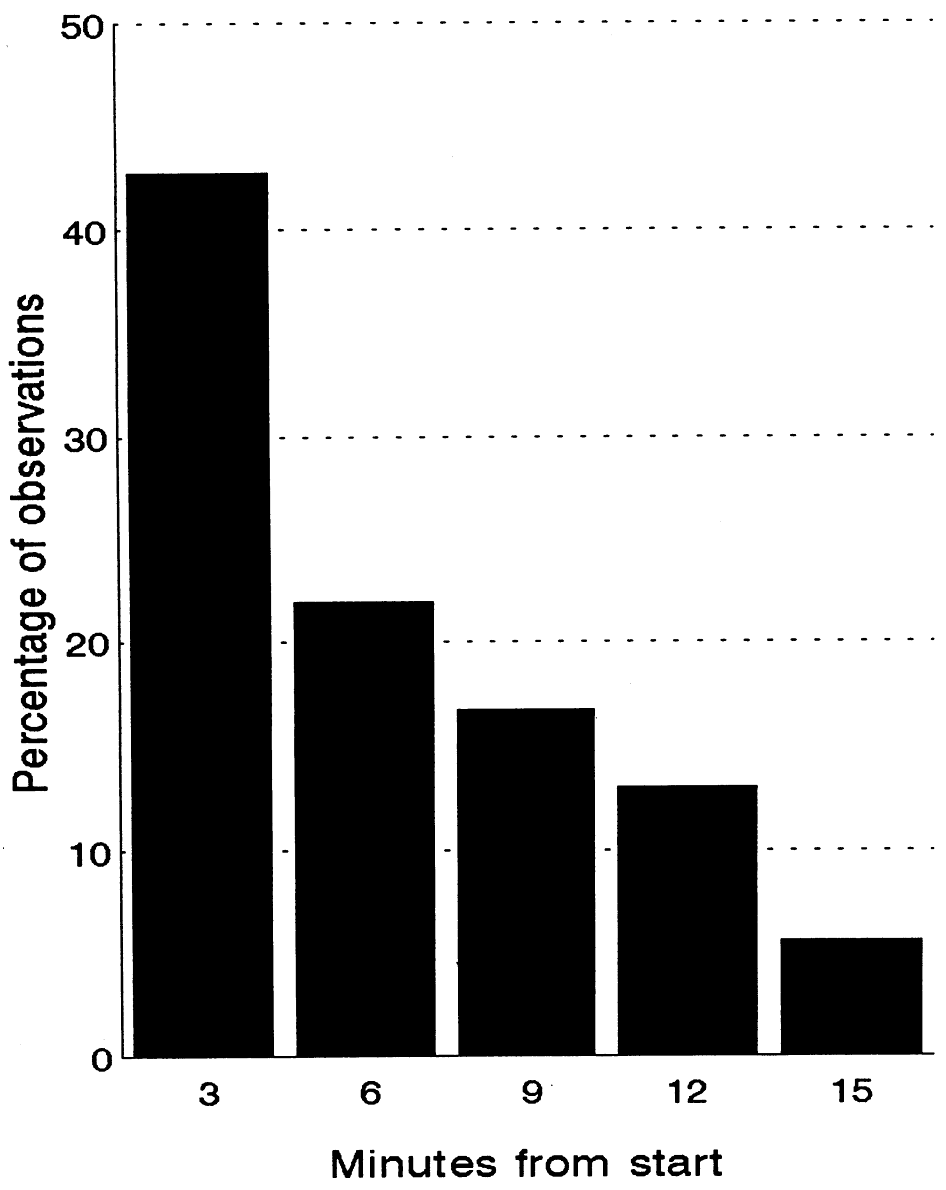
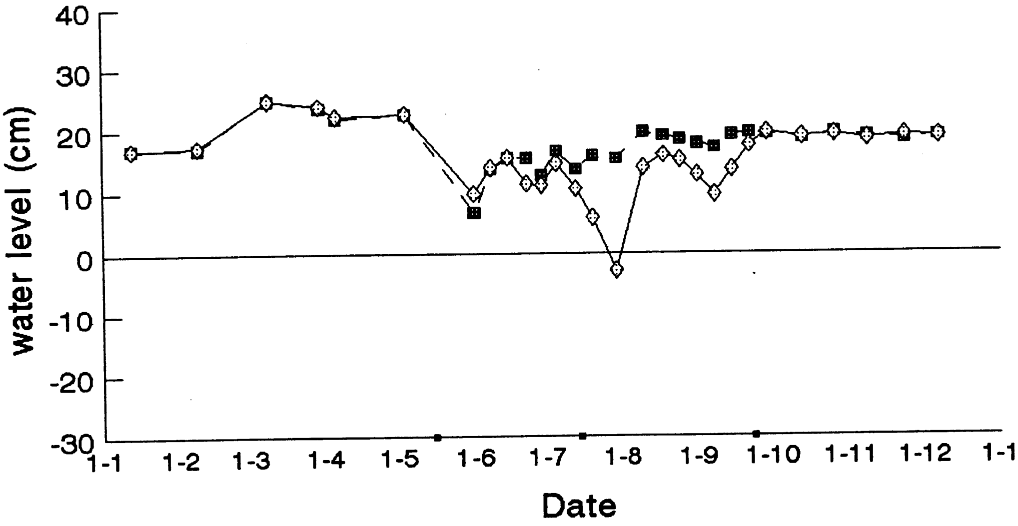


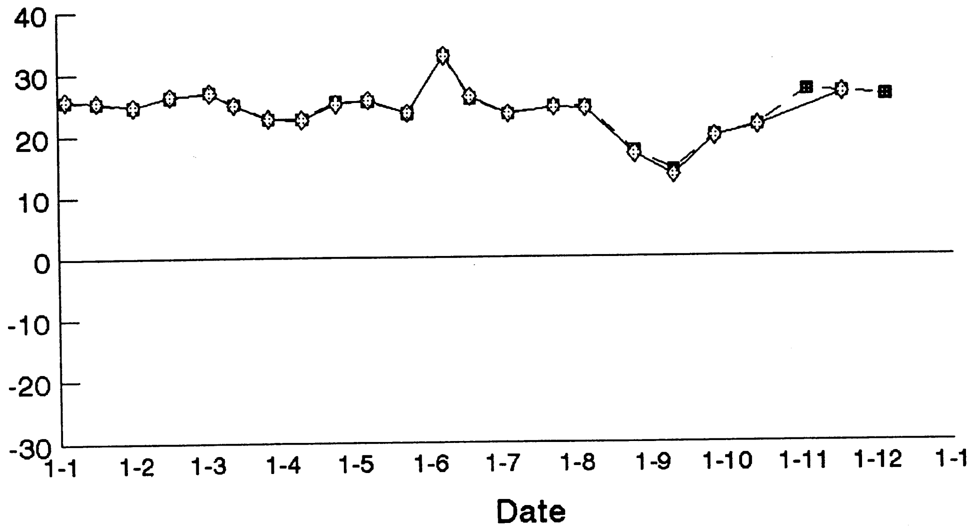
Fig.5 Percentage of total number of observations (215) in each three minute interval during 15-minute point counts

a) Little Fen 1999



unirrigated — irrigated

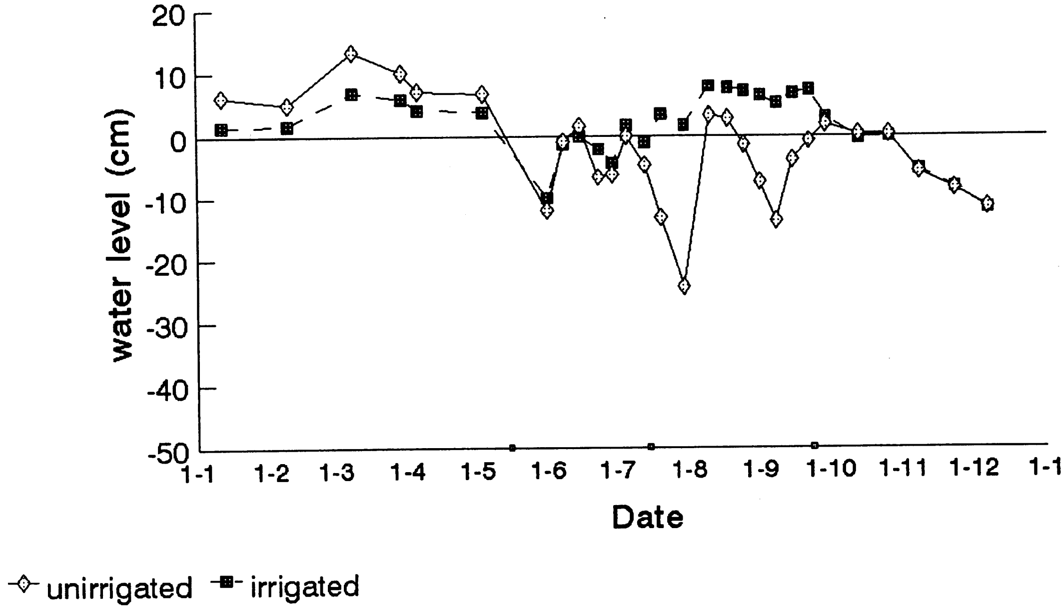
b) Little Fen 2000



unirrigated — formerly irrigated

Fig.6 Mean water levels in pools censused on Little Fen in 1999 and 2000. Horizontal line represents the April 1992 datum (Smith 1992).

a) Middle Fen 1999



b) Middle Fen 2000

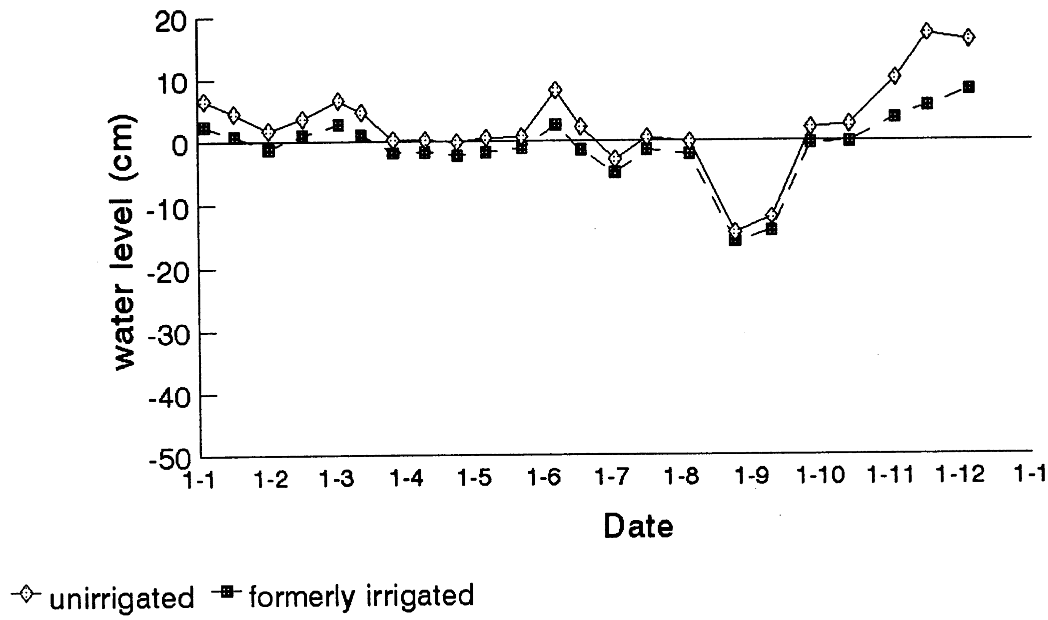


Fig.7 Mean water levels in pools censused on Middle Fen in 1999 and 2000. Horizontal line represents the April 1992 datum (Smith 1992)

Part 3:
The Status and Conservation of the fen raft spider *(Dolomedes plantarius)* at Redgrave and Lopham Fen National Nature Reserve, England

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The Status and Conservation of the fen raft spider *(Dolomedes plantarius)* at Redgrave and Lopham Fen National Nature Reserve, England

Running title: *Status and conservation of the Fen Raft Spider*

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Abstract

Dolomedes plantarius, a semi-aquatic spider, occurs at only two sites in the UK. At Lopham and Redgrave Fen NNR, ground-water abstraction between 1960 and 1999 dried out the pools on which the spider depended, reducing its range by over 80% and leaving two small, isolated populations. A population index, based on systematic monitoring from 1991 to 1999, showed significant variation between years and between the two populations, one of which showed a slight but significant positive trend. Changes in the density of spiders on the pools and the numbers of occupied pools contributed to variation in the index to differing extents in the two populations. The age structure of the populations was highly variable between years and there was no relationship between the abundance of spiders and the numbers of nursery webs. Factors contributing to the persistence of *D. plantarius* at this site, and obstacles to its recovery following hydrological restoration in 1999, are discussed.

Keywords: *Dolomedes plantarius*, endangered species, fenland restoration, population monitoring, biodiversity action plans

1. Introduction

The fen raft spider (*Dolomedes plantarius*) is one of Britain's largest spiders and rarest animals. It occurs at only two sites and at one of these its population is close to extinction. As a result of its extreme vulnerability, it is classified as Endangered (Merrett and Bratton, 1991), is fully protected under Schedule 5 of the Wildlife and Countryside Act 1981 and is the subject of a Species Action Plan (UK Biodiversity Steering Group, 1999). Under-recording and taxonomic confusion with its congener, *D. fimbriatus*, make its international distribution and status more difficult to assess. Although Bonnet (1930) believed that it occurred throughout much of the Paleartic, collation of recent records suggests that it is declining and endangered over much of Western, Central and Eastern Europe (Duffey, 1995; Helsdingen, 1995).

D. plantarius is a semi-aquatic species which is dependent on water for many aspects of its life-history, including hunting, courtship and breeding. Its rarity is attributable primarily to its need for a year-round supply of standing, base-rich, mesotrophic water (Helsdingen, 1995; Duffey, 1995). Its decline results from loss and degradation of wetlands in general, and of lowland fens in particular, throughout much of its range. Although habitat loss is also likely to be the cause of its extreme rarity in Britain, nothing is known of its historical distribution. The first UK record was from Redgrave and Lopham Fen (NGR: TM 046797), at the head of the river Waveney on the Norfolk/Suffolk border, in 1956 (Duffey, 1958). The second population, on the Pevensey Levels (NGR: TQ 6605), Sussex, was not discovered until 1988

(Kirby, 1990). The lack of any reliable historical record for this species in Britain (Bristowe, 1939; Locket and Millidge, 1951) makes it impossible either to assess the extent of its decline or to account for its present highly disjunct distribution.

Whatever its history, the present fate of this species at its two UK sites reflects the wider causes of its decline. Despite both sites being RAMSAR sites and SSSIs covered partly or wholly by national and local nature reserves, and Redgrave and Lopham Fen having candidate Special Area for Conservation status (Commission of the European Communities, 1992), problems with the maintenance of water quantity and quality, and of traditional management practices, have jeopardized the *D. plantarius* populations. On the Pevensey Levels, the population has become fragmented and densities over much of its still extensive range are substantially below those in the best maintained habitat (Jones, 1992). This paper concerns the much smaller and more vulnerable population at Redgrave and Lopham Fen NNR, which is the largest remaining valley fen in lowland England (Tallantire, 1953; Bellamy and Rose, 1960). Four years after the discovery of *D. plantarius*, an artesian borehole was sunk on the boundary of the site to supply public water. Removal of 3,500 tonnes of water a day from the underlying chalk over the following four decades, exacerbated by droughts in the 1970s, '80s and '90s, progressively dried out and degraded the fen. A hydrological regime controlled by rainfall patterns and inflow of eutrophic water from a catchment dominated by intensive pig farming, replaced the fen's formerly copious supply of base-rich, nutrient-poor artesian groundwater which rose from marginal springs and seepage lines. Internationally rare plant assemblages were degraded or lost, together with many rare species of plants and invertebrates (Harding, 1993a; Fojt and Harding, 1995).

D. plantarius is one of very few of the fen's national rarities to survive this period. Its main habitat is the margins of small, deep pools, created by traditional peat digging for fuel (Tallantire, 1953), amongst formerly extensive beds of great fen sedge (*Cladium mariscus)*. It is almost certainly the depth of these pools, enabling them to hold water even in dry summers, that enabled to spider to survive as the fen began to dry out. Despite mechanical excavation of additional deep pools to provide standing water for the spiders in the 1970s (Duffey, 1977) and 1980s, the droughts of the late 1980s left very little standing water on the fen and *D. plantarius* became confined to two, small, isolated areas (Duffey, 1991). In 1991 a Species Recovery Programme (SRP) project was initiated by English Nature with the aim of preventing extinction of the residual population: significant expansion was not a realistic objective whilst the fen remained dry. Systematic monitoring (Duffey, 1991) and positive habitat management measures were established. These included re-instating cutting of *C. mariscus* on a traditional rotation, scrub removal, excavation of additional pools and deepening of existing ones and, most radically, the introduction of an irrigation supply, piped from the borehole to the core of the spider population (Duffey, 1991; Smith 1992-1998).

The results of the monitoring work from 1991 to 1999 are the main subject of this paper. The contraction in the spiders range prior to 1991 is assessed from historical records. The borehole closed in July 1999, at the end of a 5-year programme to restore the fen by a combination of extensive removal of scrub, stripping of oxidized surface peat and grazing (Harding, 1993b; Suffolk Wildlife Trust, 1995). The likelihood of recovery of the *D. plantarius* population following the bore-hole closure is discussed, together with the requirements for its future conservation at this site.

2. Methods

2.1 Water levels

Surface water levels in the pools included in the monitoring programme were measured against permanent posts, using an arbitrary datum established in April 1992. Measurements were made to coincide with the spider census rounds but the timing and frequency of additional measurements varied from year-to-year.

From August 1991 onwards, water was piped from the borehole to a line of pools in each of the spiders two remaining centres of population, on Little Fen and Middle Fen (see 3.2 and Fig. 1), during the summer months. The timing and rate of supply varied from year-to-year (Duffey, 1991; Smith, 1992-1998). In most analyses, pools in direct receipt of irrigation have been classified as 'irrigated' and the remainder as 'unirrigated'. On Middle Fen the unirrigated pools were completely unaffected by the water supply but on Little Fen the distinction between irrigated and unirrigated pools was less clear-cut. Pools in the hinterland of the irrigated pools received water filtering back through the peat but the extent of this varied with the volume supplied and the evaporation rate.

Monthly measurements of ground water levels have been made continuously since 1983, and intermittently between 1976 and 1983, using a network of 50 piezometer tubes located throughout the fen complex (Suffolk Wildlife Trust, unpublished data). Six piezometers are sunk into the chalk aquifer but the remainder only penetrate the surface and drift deposits. The data presented in this paper are the highest monthly mean recorded between November and April (winter maximum) and the lowest monthly mean recorded between May and September (summer minimum).

2.2 Distribution

Between 1991 and 1999 the systematic monitoring of *D. plantarius* (below) provided information on changes in the spiders distribution within and around their two core areas. In addition to these data, the boundaries of their range were verified and the assumption that they were confined to these areas was checked by a large-scale search of pools in all parts of their former known range, in 1994 (Smith, 1994), and by casual observations in all years. Their distribution between their discovery in 1956, and 1991, has been pieced together from archival casual records and one-off surveys of specific areas of the fen (e.g. Moore, 1977; Orr, 1977; Kennet, 1985; Thornhill, 1985). Losses from specific areas are recorded as the year in which spiders were last seen: searches were made in all of these localities at later dates confirming absence. The spiders likely distribution prior to 1956 has been assumed from the distribution of substrates which reflect the presence of standing water and were likely to have supported suitable vegetation (Price, 1979).

2.3 Population monitoring 1991-1999

Small populations of cryptically-coloured, semi-aquatic invertebrates, such as *Dolomedes plantarius*, inhabiting tall, dense, sometimes flooded vegetation, are intrinsically difficult to census. Because accurate estimates of total population size were impracticable, the methodology was based on measuring and indexing annual variation in population size. From 1993 to 1999 the survey methodology was highly standardized (Smith, 1993). A single census was carried out in late July, which is the peak period for the construction of nursery webs in which the spiders rear newly-hatched young. Three replicate counts were made, where possible on consecutive days, at a randomized sample of pools in the spiders two centres of population (31 pools on Little Fen, 30 on Middle Fen) (Fig. 1). The sample comprised pools both with and without a direct irrigation supply. To enable detection of any expansion in range, the census area included pools contiguous with, but beyond, the known range of the population.

In 1991 and 1992 the pools censused were chosen subjectively from amongst those that held water in the core of the spiders range in 1991, on the basis of characteristics thought likely to make them suitable for *D. plantarius* (Duffey, 1991). In 1991 weekly counts were made at 29 pools on each Fen from mid-May to mid-August (Duffey, 1991). In 1992 counts were made approximately every three weeks from late April to the end of September (Smith, 1992). To maximize overlap between the 1991-1992 and later data set, all of the 1991-1992 pools were monitored until 1995, after which only the randomized sub-sample was retained.

Counts were made on bright days between 1000 and 1730 hrs. Each pool was searched by wading slowly round in the water searching the marginal emergent and floating vegetation. Records were made of the body length of all spiders, sex of adults and sub-adults, stage of the breeding cycle of adult females, the location and height of nursery webs and the plant species in which they were constructed.

2.4 Analyses of population trends

Spiders were classified into three body length categories (<=8 mm 'small', 8-15 mm 'medium', >=15 mm 'large'). For each category the highest of the three replicate counts made at each pool was taken as the best estimate of the numbers of spiders. The total maximum count for each pool was obtained from the sum of the maximum number in each size category.

Analysis of population trends was carried out using generalised linear models with the maximum count for each pool in July as the response variable. Log-linear Poisson regression models were fitted as implemented in program TRIM (Pannekoek and van Strien, 1998). The underlying model is similar to several other indexing methods (e.g. Mountford, 1982):

$$\text{Expected count} = \text{Site effect} * \text{Year effect}$$

or the log-linear equivalent:

$$\log(\text{expected count}) = \log(\text{site effect}) + \log(\text{year effect}).$$

TRIM allows the data to be split into different strata. In this context each pool constitutes a site or plot and Little and Middle Fens form separate co-variate strata. The model allows sites to be censused in some years and not others and so both the 1991-1995 and 1993-1999 census data could be utilized.

The program fits five standard models: (i) no time (year) effects; (ii) linear trend (in log numbers); (iii) linear trends within covariate strata (linear trends differ between Little and Middle Fen); (iv) time effects (separate effects for each year); (v) time-effects within covariate strata (year effects differ between Little and Middle Fen).

Overdispersion and serial correlation in the data, which can seriously bias model selection and the precision of parameter estimates, were investigated. Correction was made for overdispersion but first order serial correlations were low.

2.5 Analyses of the effects of water levels on numbers counted

The possible effects of water level on the numbers of spiders counted were tested using generalized linear models similar to those used to calculate the population indices. Counts were modelled as functions of pool (included in all models), year, fen and water level, using Poisson errors and a log link function. In all cases a correction for overdispersion was applied by estimating the scale parameter as the square root of Pearson's chi-squared divided by the number of degrees of freedom. Linear and curvilinear effects of water level were tested by using water level and water level^2 as predictor variables. Data from 1992 to 1999 for pools with at least two annual counts (including at least one non-zero count) were used for this analysis (65 pools). All models were fitted using SAS PROC GENMOD (SAS, 1996). Type 3 tests, which control for the effects of other factors in the model, were used to test the effects of individual factors.

3. Results

3.1 Water levels

Over the period 1976 to 1999, ground water levels showed a trend towards increasingly low levels in summer and poor recharge in winter (Fig. 2). The droughts of 1989 to 1992 and 1995 to 1997 are particularly prominent. Summer water levels in 1999 were the highest on record but reflect exceptional rainfall rather than the effects of the July borehole closure.

Surface water levels measured in the unirrigated pools also show clearly the extreme effects of the summer droughts in 1992 and from 1995 to 1997 (Fig.3), during which many census pools dried up. In mid-July 1996, for example, 21 of the 30 pools on Middle Fen and 14 of the 31 pools on Little Fen were dry. In general, summer water losses appear to be greater on Middle than on Little Fen but this reflects in part the indirect effect of the irrigation water in raising water levels in some 'unirrigated' Little Fen pools (2.1 above).

Artificial irrigation was more effective in maintaining high water levels on Little Fen than on Middle Fen (Fig.3). Only in 1998 was there substantial summer draw-down in irrigated pools on Little Fen whereas on Middle Fen water loss from irrigated pools was sufficient to leave much of the emergent marginal vegetation stranded in 1992, 1995, 1996 and 1998.

3.2 Distribution

The distribution of substrates likely to reflect water levels and vegetation suitable for *D. plantarius,* when the fen's hydrology was relatively intact, suggests that the species was likely to have been widely distributed in all four of the fens that comprise what is now the 123 ha Redgrave and Lopham Fen NNR (Fig. 1). Its recorded distribution from 1956 onwards is patchy, probably reflecting, initially, the sporadic and localized nature of recording and inaccessibility of parts of the site because of the high water table. By the 1970s and 1980s, however, as the fen became drier, the frequency of casual recording increased and numbers of locations for spiders decreased giving a clear indication of a contraction in range (Fig. 1). Some records of visits make it clear that former sites had become unsuitable through loss of standing water and invasion by dense scrub (e.g. Duffey, 1991; Thornhill, 1985). By 1990 *D. plantarius* probably occupied only around 15% of its likely former range and 30% of its recorded historic range.

By the late 1980s this contraction in range had left two isolated populations separated by a distance of >0.5 km (Fig. 1). In most years the spiders on Middle Fen were confined to an area of deep, machine-dug pools. Some of these were unirrigated but these dried up in 1995 and the spiders were further confined to the irrigated area of the Fen (*c.* 0.95 ha) (Table 1).

Twelve new pools excavated within the irrigated area in spring 1996 were successfully colonized by 1997. In 1999, following a wet winter, spiders recolonized the part of the unirrigated area closest to the irrigated pools (Table 1), a maximum distance of 100 m.

In contrast to Middle Fen, the presence of more, deeper peat diggings on Little Fen allowed the spiders to retain a distribution further away from the irrigation source during the 1990s. The maximum extent of this population during the 1990s was *c.* 3.75 ha. The irrigation supply affected water levels in pools up to about 100 m from the outlets. In very dry years the population contracted to occupy pools within this area, usually expanding again after wet springs (Table 1). Thus, the numbers of occupied pools increased in 1995, following the wet summer and winter of 1994, and contracted again during the drought of 1995 to 1997. However, this relationship was not simple: for example, there was no evidence of an increase in pools occupied on Little Fen in 1994, following the wettest winter of the decade.

3.3 Population trends

The population indices from 1991 to 1999 show substantial and significant fluctuations between years (Fig. 4). The TRIM model that best fitted the data was the most complex, time-effects model within co-variate strata. This indicates that whilst there was significant variation in population size between years, the pattern of annual variation differed significantly between the Little and Middle Fen populations (Wald test: $F_7=78.62$, $p<0.001$). However, separate analyses for the two Fens suggest a positive trend in numbers over this period on Little Fen but not on Middle Fen (Wald test for significant slope: $F_1=35.64$, $p<0.001$). Examination of the data also suggests that the annual pattern of variation in the two populations has become more synchronous since 1997 (Fig. 4).

Mean numbers of spiders on occupied pools on Middle Fen were higher than those on Little Fen in all but one of the nine census years, despite a similar range of pool sizes on both fens (Fig. 5). It is difficult to quantify densities per unit bank length because the latter varies substantially, and in a non-linear manner, with changing water levels. However, density estimates, based on measurements of bank lengths of some pools at intermediate water levels, give maximum densities in the order of one spider per 0.6 m of bank. These were very exceptional, however: more typical densities were in the order of one spider per two or three metres of bank, or less.

Both changes in range (numbers of occupied pools) and in the numbers of spiders per pool contribute to the variations in population size shown by the index. On Little Fen, variation in the numbers of pools occupied closely mirrored the variation in the index (see Fig.4: Pearson Correlation coefficient, $r_7=0.876$, $p<0.01$). On Middle Fen, however, changes in numbers of pools occupied were relatively small (Table 1) and showed no significant correlation with the index ($r_7=0.074$, ns). Changes in numbers of spiders per pool were smaller on Little than on Middle Fen (Fig. 5) but on both Fens these were closely correlated with the index (Little Fen; $r_7=0.925$, $p<0.01$: Middle Fen; $r_7=0.949$, $p<0.01$).

3.4 Population structure

The size composition of the spider population, as well as the totals counted, varied substantially between years and between Fens. Over the seven years for which comparable data are available, the proportion of the population comprised by the three size classes was very variable (Table 2). The pattern of size variation across years differed significantly between Little and Middle Fen (G-test: $\chi^2_{12}=45.16$, $p<0.001$) and on each fen the size distribution differed significantly between years (G-tests: Little Fen; x^2_{12}=63.12, $p<0.001$: Middle Fen; x^2_{12}=75.65, $p<0.001$).

Annual variation in numbers in the size classes reflects only weakly the expectations based on life-history. At Redgrave and Lopham Fen most *D. plantarius* are thought to grow during their second year and to mature and breed the following year. Thus, successful breeding seasons might be expected to result in a large 'medium' size class the following year and in relatively large numbers of adults that year after that. However, inspection of the data shows little evidence that the relative size of cohorts resulting from good breeding seasons is maintained to maturity. The relatively long life-span might be expected to result in adults comprising a relatively small proportion of the population. Although the 'large' size class, most of which was adult, comprised a smaller proportion of the population than the 'medium' size class in most years, it was conspicuously smaller only in years with high total counts (Table 2).

There is no evidence of any significant relationship between the size of the spider population and indicators of the success of the breeding season (Table 2), despite the census falling within the peak period for web-building (82% of webs found in 1992 and 1999, when web numbers were recorded at consistent frequency throughout the season, were built in late-July and early August). Spearman rank correlation coefficients for the relationship between annual maximum counts of adult females and numbers of nursery webs were 0.271 for Little Fen, 0.359 for Middle fen and 0.280 for both combined (n=7, ns in all cases). Those between the annual maximum counts of all spiders and those of adult females were 0.564 for Little Fen, -0.054 for Middle Fen and 0.174 for both combined (n=7, ns in all cases).

3.5 Distribution across pools

Some occupied pools were consistently favoured by *D. plantarius*. The significance of agreement in the abundance rankings for pools in different years was tested using the Kendall coefficient of concordance (Siegel, 1956) for comparable sets of pools (1991-1995 and 1993-1999 census samples), excluding pools on which no spiders were ever recorded. These were highly significant for both sets of pools (Table 3). This effect is unlikely to be attributable primarily to variation in pool size because both large and small pools showed consistent trends in numbers. Formal analysis of this relationship is again difficult because of the effect of changing water levels on pool size. Although loss and recolonisation of spiders on pools which received no irrigation water (3.2 above) may also contribute to the concordance, the significant result for the 1991-1995 sample of pools from Little Fen, all of which were in direct receipt of irrigation water, suggests that it is unlikely to be important: even within areas where water levels were maintained, some pools appear to have supported consistently more spiders than others.

There is also some evidence that the distribution of nursery webs, in which the females hatch their eggs and guard their young, was significantly clumped. Departure from a random distribution of webs amongst pools was tested against a Poisson distribution. Pools on which webs were never recorded were excluded from the analysis because it is not known whether zero data imply that pools were unsuitable or simply that webs were absent. Significant departure from this zero-truncated Poisson distribution (Greenwood, 1996) was found amongst the combined data from all years (x^2_1=5.77, $p<0.05$). This distribution appears to reflect the distribution of spiders. In general, more webs were found on pools with the highest numbers of spiders: the rank correlation between the number of webs and the maximum count of spiders on each pool, using data from the July census in all years, is significant (Spearman: r_{211}=0.32,

$p<0.001$). The same relationship is found in the data from 1992, when counts were made throughout the year and a higher proportion of webs was likely to have been detected (Spearman: $r_{59}=0.63$, $p<0.001$).

At Redgrave and Lopham Fen, nursery webs are built in stiff-leaved emergent vegetation, between 0.1 and 1 m (mean=0.52 m, SE $\pm$ 0.02 m, $n=99$) above the water. Where more than one nursery web was found on a pool, the distribution within that pool was often clumped, with distances as little as 0.2m between webs. Proximity of webs can result from the same female breeding twice in the season, but clumping of webs was also encountered when different females built at the same time.

3.6 The effects of water level on numbers counted

Modelling the effects of water level on numbers of spiders counted suggested that such effects were weak. Initially, 15 different models involving possible effects of year, fen and water level were fitted. Inspection of the model fits indicated that models which included separate annual effects for Little and Middle Fen consistently provided the best descriptions of the data and that any effects of water level were weak.

When year effects were omitted from the models there was a significant curvilinear effect of water level on spider numbers (water, $p=0.0088$; water^2, $p=0.0019$), which peaked at intermediate water levels. Under this model the relationship between spider numbers and water level did not differ significantly between Fens (interactions of: water*fen, $p=0.5130$; water^2*fen, $p=0.3525$). When year effects which differed between fens were included in the model, the curvilinear effect of water level was marginally non-significant (water, $p=0.0503$; water^2, $p=0.0711$). Again the relationship between spider numbers and water level did not differ between fens (interactions of: water*fen, $p=0.4898$; water^2* fen, $p=0.3405$). The parameter estimates for the effects of water level on spider numbers were similar in the models with and without year effects (without year; water=0.0861, water^2=-0.0006: with year and year*fen interaction; water=0.0804, water^2=-0.0004). Thus, the relationship between numbers of spiders counted and water level did not appear to be confounded by year effects. The low numbers of spiders counted at very low water levels may have been due either to spiders moving into damp vegetation, or to mortality, but the decrease in numbers counted between intermediate and high water levels may have resulted from increased opportunities for spiders to move away from the study pools.

Although the effect of water level on spider numbers was weak, it was important to test whether it could bias the annual population indices to an appreciable extent. Year effects from models with and without the effects of water level were extremely similar and highly correlated (Little Fen; $r^2=0.993$; Middle Fen $r^2=0.965$). The coefficients for the effects of water and water^2 from the model without year effects were slightly higher than those from the model with year effects (above). A further model was therefore fitted in which the relationship with water level was based on the coefficients from the model without year effects, fitted as an offset. Again the annual indices were very similar and highly correlated (Little Fen, $r^2=$ 0.978: Middle Fen, $r^2=0.994$). Thus the annual indices appear to be robust to the effects of water level that were detected by this analysis.

4. Discussion

4.1 Population trends

Since 1960 the *Dolomedes plantarius* population at Lopham and Redgrave Fen has declined dramatically and fragmented, surviving in two, small, isolated areas since the end of the 1980s. This decline correlated with the drying-out of the fen as a result of artesian extraction compounded by droughts. Major changes in vegetation, particularly encroachment of scrub and secondary woodland and decline in *Cladium mariscus*-dominated fen, have resulted not only from hydrological change but also from cessation of traditional management practices (Fojt and Harding, 1995). These are also likely to have contributed to the loss of *D. plantarius* but the historical data are inadequate to assess the relative importance of these different factors.

After the severe drought of the late 1980s the spiders were confined to deep machine-dug pools and old peat cuttings. Throughout the 1990s the residual populations fluctuated in size but showed little evidence of any sustained increase. Whilst there is some evidence of a positive trend on Little Fen in the second half of the decade, the large increases seen in 1995 and 1998, particularly on Middle Fen, have not been sustained. Modelling of the impact of water levels on numbers of spiders counted suggested that the indexing method used during this period was robust to the effects of changing water levels. However, a slight negative bias in numbers of spiders counted when water levels were high, which presumably resulted from dispersal amongst flooded vegetation beyond the pool margins, suggests that the methodology may need to be revised in the future, if extensive flooding becomes the norm.

Although total population size could not be accurately estimated, it is clear from the size of the area occupied and the proportion of sufficiently deep pools included in the census, that the adult female population is small. If a very high probability of detection is assumed, estimates vary from <10 adult females in 1993 to *c.* 75 in 1997. Adult females are relatively easy to detect because of their size and behaviour during the breeding season but even if a 50% detection rate is assumed, the population estimate is precariously small.

In addition to the small size of the population, the large annual variability in its age-structure and its failure to conform to expectations based on life-history, suggest that its dynamics are complex and highly variable. Because of the spiders longevity, impacts on a cohort in any one year will affect numbers in future years, making the relationship between environmental conditions and spider numbers very complex. Frequent but unpredictable variations, particularly in water levels, both within and between years are likely to have impacted differently on different age-groups because of their differing requirements for mobility, food availability, overwintering conditions and predator avoidance.

This is clearly illustrated in the case of breeding females, for which there was no significant relationship between annual abundance and the success of the breeding season (judged by numbers nursery webs). Successful breeding is highly dependent on water levels. Not only must the female be able to dip her egg sac in water every few hours during the *c.* three week period when she carries it under her body (Bonnet, 1930; Bristowe, 1958), she must also have stiff-leaved, emergent vegetation in which to construct her nursery web. Of 103 nursery webs recorded at Redgrave and Lopham Fen over the nine year study, all were built in vegetation directly above the water (Smith, unpublished data). The draw-down in dry summers frequently leaves marginal emergent vegetation stranded and results in breeding failure even when water remains in the deepest parts of the pools. One reason for the significant difference in annual variation in the population indices for Middle and Little Fens is the more sustained and severe decline on former than the latter fen following the 1995 peak. This almost certainly resulted from breeding failure when water levels in the irrigated pools on Middle Fen fell to exceptionally low levels in late summer 1995, and in 1996.

The large annual variations in densities of spiders suggest that in most years pools are well below their potential carrying capacity. In some years low water levels reduce the carrying capacity but usually spider numbers reflect conditions in previous years (above). There is no evidence that territoriality limits densities of *D. plantarius* within the range of densities encountered. Although there is likely to be a minimum spacing for water-edge hunting perches, this must be at or below the spacings encountered on favoured pools in peak years. Even in the best-populated pools, densities were less than a quarter of those reported for optimal habitat in the Netherlands (Helsdingen, 1995). The close proximity of nursery webs on the same pools suggests that territoriality in breeding females is also negligible and is unlikely to limit breeding success even when suitable sites are limited by low water levels.

4.2 Factors contributing to the persistence of the population

Several extrinsic and intrinsic factors appear to have contributed to the persistence of this tiny and highly vulnerable population during the 1990s. First, a suite of measures increased the availability of standing water in dry summers. Of these, the artificial irrigation of the pools appears to have been critically important. During the 1990s, the spiders became restricted to irrigated pools in dry summers. The deepening of pools to increase the numbers holding water is also likely to have improved survival in the driest summers. The excavation of new pools within the irrigated zones may also have benefited population size. This is particularly likely on Middle Fen where numbers of irrigated pools were relatively small and increases in population size resulted largely from increases in density, suggesting that pool numbers might eventually limit population growth. In contrast, increases on Little Fen tended to be absorbed by increasing the occupancy of the many old peat diggings in the irrigated zone.

Secondly, management to maintain the structure and species composition of emergent and marginal vegetation is likely to have been beneficial. However, because most of the vegetation management was not done on an experimental basis, and information on preferences on which it was based is mostly circumstantial, it is difficult to assess its impact. Scrub was removed from the pool banks, and tall emergent common reed *(Phragmites australis)* from the pools, because the *D. plantarius* is thought to prefer open sunny pools. Thornhill (1985) noted that spiders were absent from pools amongst willow scrub but the lowered water table and other vegetation changes associated with scrub invasion make causation difficult to establish. Even prior to the introduction of irrigation, *D. plantarius* was largely confined to areas dominated by *C. mariscus*. Dominance of *C. mariscus* has traditionally been maintained by summer mowing on a 3-4 year rotation. This was reinstated throughout the core spider areas in 1992. The stiff leaves of this sedge appear to provide an ideal structure for the construction of nursery webs: 74% of nursery webs were constructed in *C. mariscus* and a further 21.4% in mixed fen vegetation including *C. mariscus* (Smith, unpublished data). Although other species were dominant towards the edges of the spiders range, isolated clumps of *C. mariscus* were selected for nursery web construction.

Thirdly, intrinsic features of the life-history of *D. plantarius* are likely to have enabled it to endure extreme conditions in some years. Fecundity in *D. plantarius* is high: infertile eggs sacs, and sacs abandoned in late summer, both of which tend to be atypically small, contained between 240 and 327 eggs (Smith, unpublished data) but sacs with 600 to 700 eggs are reported in the literature (Bonnet, 1930; Wiebes, 1959). Thus, even very small numbers of successful breeding attempts have the potential substantially to increase population size.

Breeding success can be further augmented by second breeding attempts (Smith, 1992). Although such attempts at Redgrave and Lopham Fen are less likely to be successful than first and produce fewer young, they can potentially enable some successful breeding in years when first attempts fail because of low water levels. In years when both broods succeed, they can very substantially boost population size. The relatively long life-span of *D. plantarius* (above) has almost certainly been another critical factor in preventing its extinction because it enables it to tolerate complete breeding failure in any one year - although not in two successive years. Breeding success must have been extremely poor between 1988 and 1991 and numbers of nursery webs recorded in several subsequent summers were very low. All of these features of *D. plantarius* may represent an adaptation to the unpredictability of summer water levels in lowland wetlands.

Finally, such a small population is likely to be very vulnerable to stochastic extinction (Shaffer, 1987): its persistence through the 1990s must therefore, to an extent, be seen as resulting from stochastic good fortune.

4.3 Obstacles to recovery

Whilst the cessation of artesian extraction may represent a turning-point for the survival of the *D. plantarius* population, it does not guarantee recovery. A suite of problems remains. First, predictions of the extent and timing of the hydrological recovery vary. During the recovery period summer water levels may remain inadequate to sustain a breeding population, requiring the maintenance of artificial irrigation. Full hydrological recovery should result in the sedge beds remaining flooded for much of the summer and decrease the dependency of *D. plantarius* on deep pools. However, if the recovery proves inadequate to sustain summer water levels, the long-term maintenance of the *D. plantarius* population is unlikely to be viable.

Second, although there is clear evidence that water availability has been of overriding importance in the decline of *D. plantarius*, there is circumstantial evidence that water quality may become a limiting factor in its recovery. The data in this paper suggest that pools vary in their attractiveness to *D. plantarius*. A study of water chemistry in 1991 showed substantial differences between pools in all of the variables measured (pH, oxygen, biological oxygen demand, soluble reactive and total phosphorus) but the relationship between these variables and numbers of spiders on individual pools was not investigated (Dolman, 1991; Duffey, 1991). The same study showed evidence of pollution, in the form of high total phosphorus, high biological oxygen demand and low dissolved oxygen, in the agricultural drain which enters Little Fen. Direct effects of this pollution on the hibernating Little Fen population could account for its failure to expand in range or numbers after the drain overflowed and flooded the fen in early spring 1994: the Middle Fen population expanded much more rapidly during the same period. In the Netherlands, agricultural pollution is believed to result in loss of *D. plantarius* but, again, there is no quantitative supporting evidence (Helsdingen, pers. comm.).

Eutrophication is also likely to be a cause of the sharp decline in *C. mariscus* on the fen since the mid-1990s (Parmenter, 1999). This decline presents a major threat to the recovery of the spider population. Within the core spider areas, there is evidence that the replacement of *C. mariscus* by *P. australis* around individual pools is associated with loss of spiders (Smith, unpublished data).

The removal of oxidized peat from *c.* 19% of the fen surface has also created large areas of *P. australis*-dominated vegetation and open water which are likely to remain unsuitable for re-colonisation by *D. plantarius* for many years. These areas are also likely to act as physical barriers to the recolonisation of remaining areas of suitable habitat.

Finally, the small size of the population, and the likelihood that it has been through several tight genetic bottlenecks, raises the possibility that it could become endangered through lack of genetic variation (Lande and Barrowclough, 1987). The physical isolation of the two remaining centres of population almost certainly prevents any genetic exchange between them: most of the intervening habitat has been inimical to spiders for at least 20 years. DNA fingerprinting is required to establish the variation within, and genetic distance between, the populations.

The extent of these problems for the recovery of *D. plantarius* at Lopham and Redgrave Fen will become more clear if appropriate monitoring and research is maintained. Solutions to them are vital if the target set in the Species Action Plan (UK Biodiversity Steering Group, 1999) for *D. plantarius* at this site is to be achieved. This is for a ten-fold increase in range, over much of which mean densities should increase to *c.*15 individuals per pool. Translocation of spiders to parts of the fen with suitable vegetation and water levels is likely to be a critical feature of the recovery. Increasing the number of centres of population decreases the probability of stochastic extinction, circumvents the problems that physical isolation creates for dispersal and can be used to increase genetic variation by mixing individuals from the two residual populations.

The problems of eutrophication and deleterious vegetation change are more difficult to quantify and to solve. However, recolonisation of the fen by *D. plantarius* is likely to depend on the re-establishment of substantial areas of *C. mariscus*-dominated swamp as well as on hydrological recovery. Re-establishment of this internationally rare community (Commission of the European Communities, 1992) was one of the targets of the £3.6 million Fen Restoration Project (Suffolk Wildlife Trust, 1995). The success of the habitat restoration and the fate of the spiders are therefore intimately linked and both may depend on the political will to solve the problems of eutrophication and agricultural pollution.

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Table 1 Numbers of census pools on which *D. plantarius* was recorded in July each year. Irrigated pools on Little Fen include all pools which benefitted from irrigation water, either directly or indirectly (see text.

Year:		1993	1994	1995	1996	1997	1998	1999
Little Fen	Irrigated (n=16 pools)	8	8	12	9	12	14	11
	Unirrigated (n=15 pools)	2	2	4	0	1	6	4
Middle Fen	Irrigated (n=7 pools)	6	7	7	5	6	7	6
	Unirrigated (n=23 pools)	2	3	0	0	0	0	1

Table 2. Proportions of *D. plantarius* in different size classes, and maximum counts of all individuals, adult females and nursery webs, in the Little and Middle Fen census areas in July 1993-1999

	1993	1994	1995	1996	1997	1998	1999
Little Fen							
% Large	36	21	20	65	30	5	8
% Medium	57	37	66	15	41	50	53
% Small	7	42	15	20	29	45	39
Max. spider count	**14**	**19**	**41**	**20**	**66**	**94**	**62**
Max. adult females	0	1	6	6	16	4	4
Nursery web count	0	2	0	0	9	0	4
Middle Fen							
% Large	29	30	3	17	47	5	15
% Medium	33	48	62	34	53	32	46
% Small	38	22	35	49	0	63	39
Max. spider count	**21**	**44**	**102**	**41**	**15**	**99**	**52**
Max. adult females	0	8	1	5	6	5	7
Nursery web count	1	3	1	0	0	0	7

Table 3. Kendall coefficient of concordance for the numbers of spiders on the sample of pools censused from 1991 to 1995 and those censused from 1993-1999 (W: Kendall coefficient of concordance).

	Little Fen				Middle Fen			
Census:	df	*W*	X_{24}^2	*p*	df	*W*	X^2	*p*
1991-1995	22	0.39	42.65	<0.01	18	0.4	35.69	<0.01
1993-1999	23	0.5	80.35	<0.001	9	0.65	40.76	<0.001

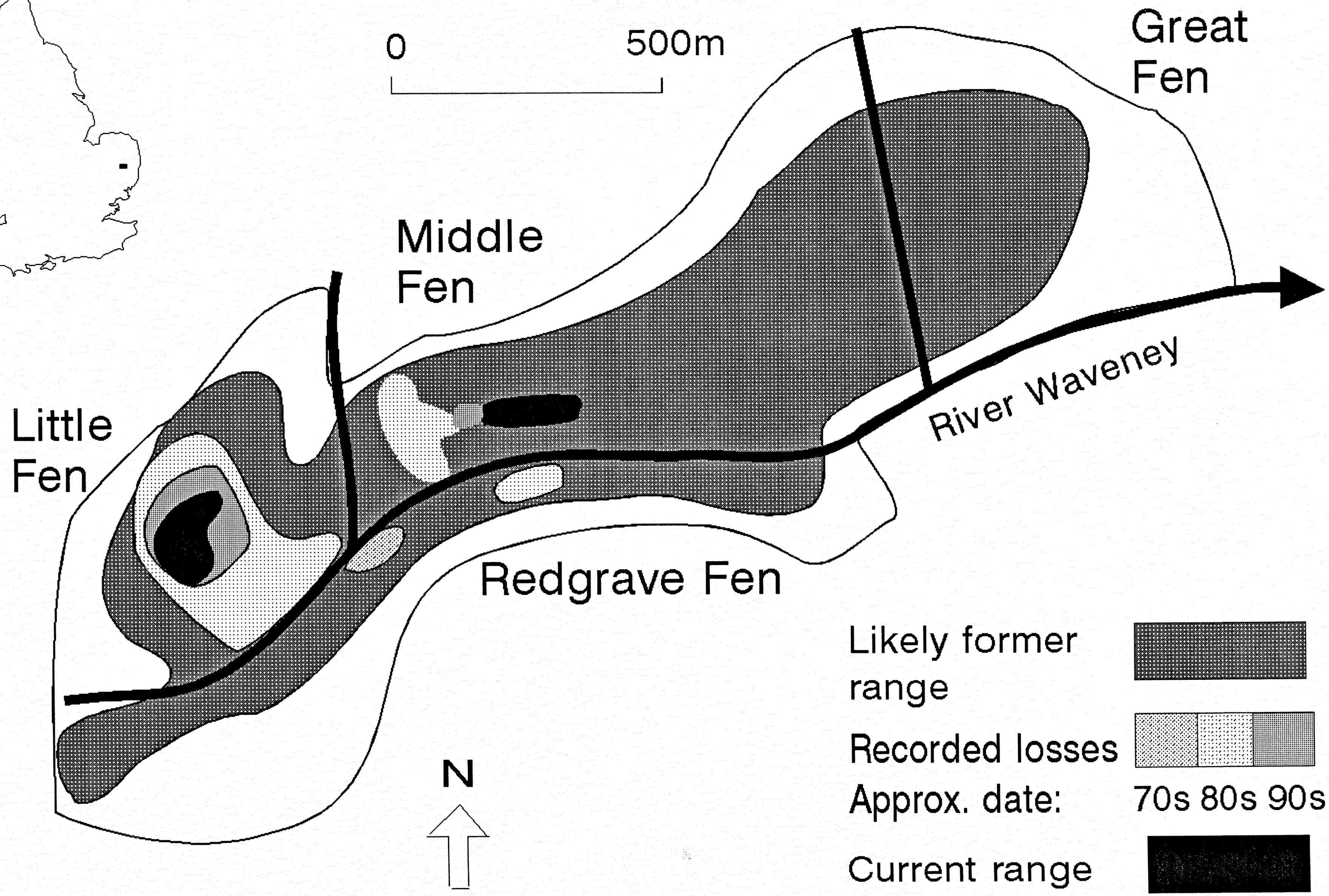


Figure 1 The distribution of *Dolomedes plantarius* on Redgrave and Lopham Fen NNR, Norfolk (location on UK inset). Little, Middle and Great Fen comprise the Lopham Fens.

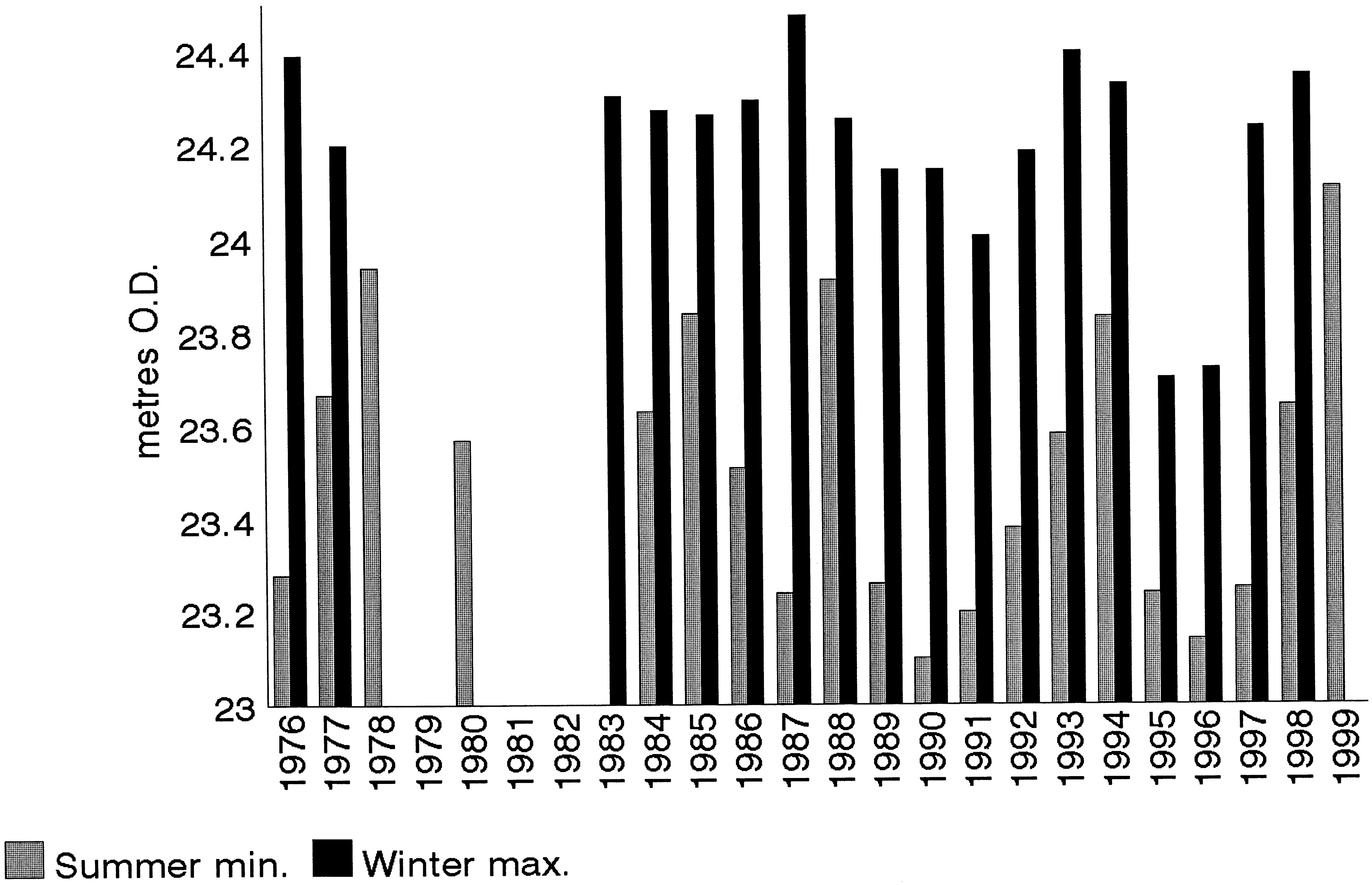
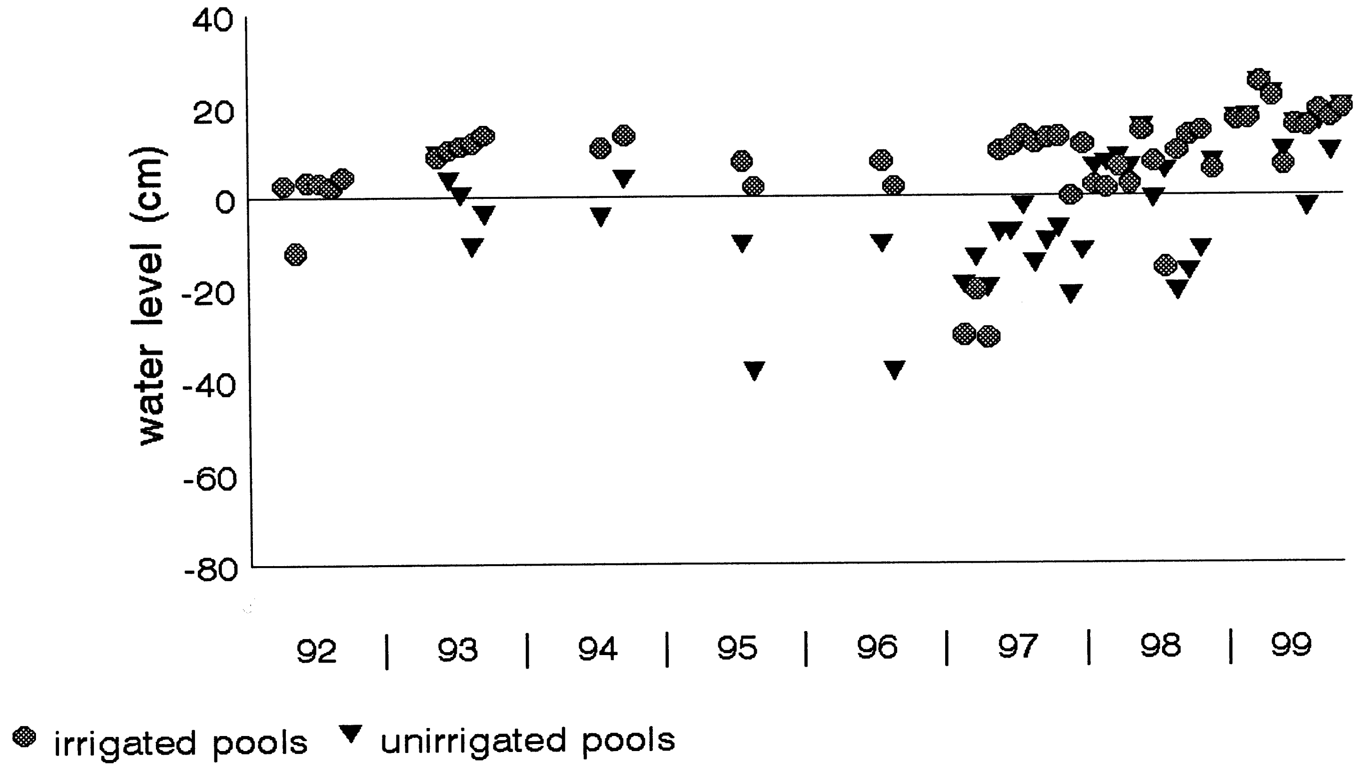


Figure 2. Mean winter maximum and summer minimum water levels in piezometer tubes from 1976 to 1999.

a) Little Fen



b) Middle Fen

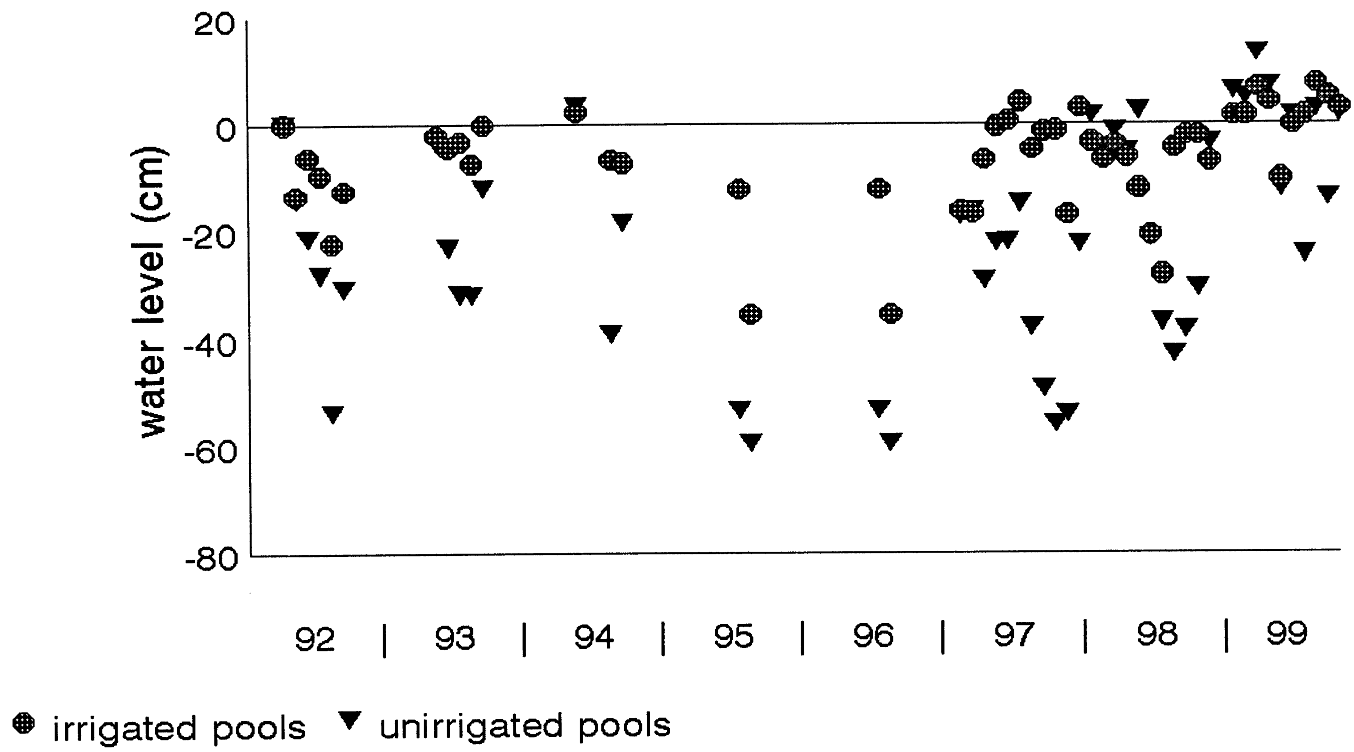


Figure 3. Mean levels in the census pools 1992-1999. Each point shows the mean level for one date each month on which measurements were made. The horizontal line represents the April 1992 datum (see text).

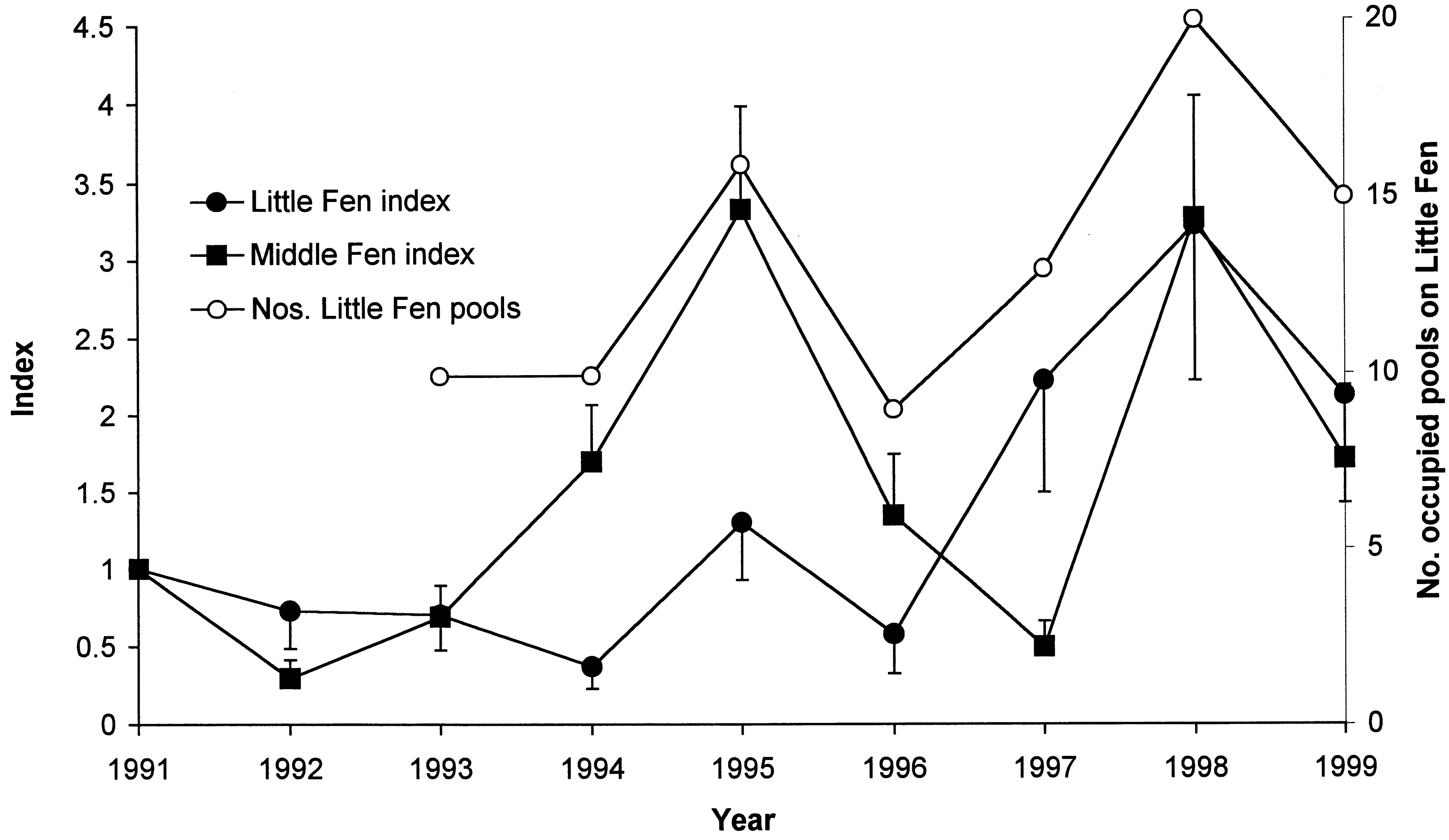


Figure 4 Annual population indices for *D. plantarius* on Little and Middle Fens (see Fig. 1) in July 1991-1999, generated by a log-linear poisson regression model and plotted on a linear scale (vertical bars denote 1 SE). Numbers of occupied pools on Little Fen from 1993 to 1999 (see also Table 1).

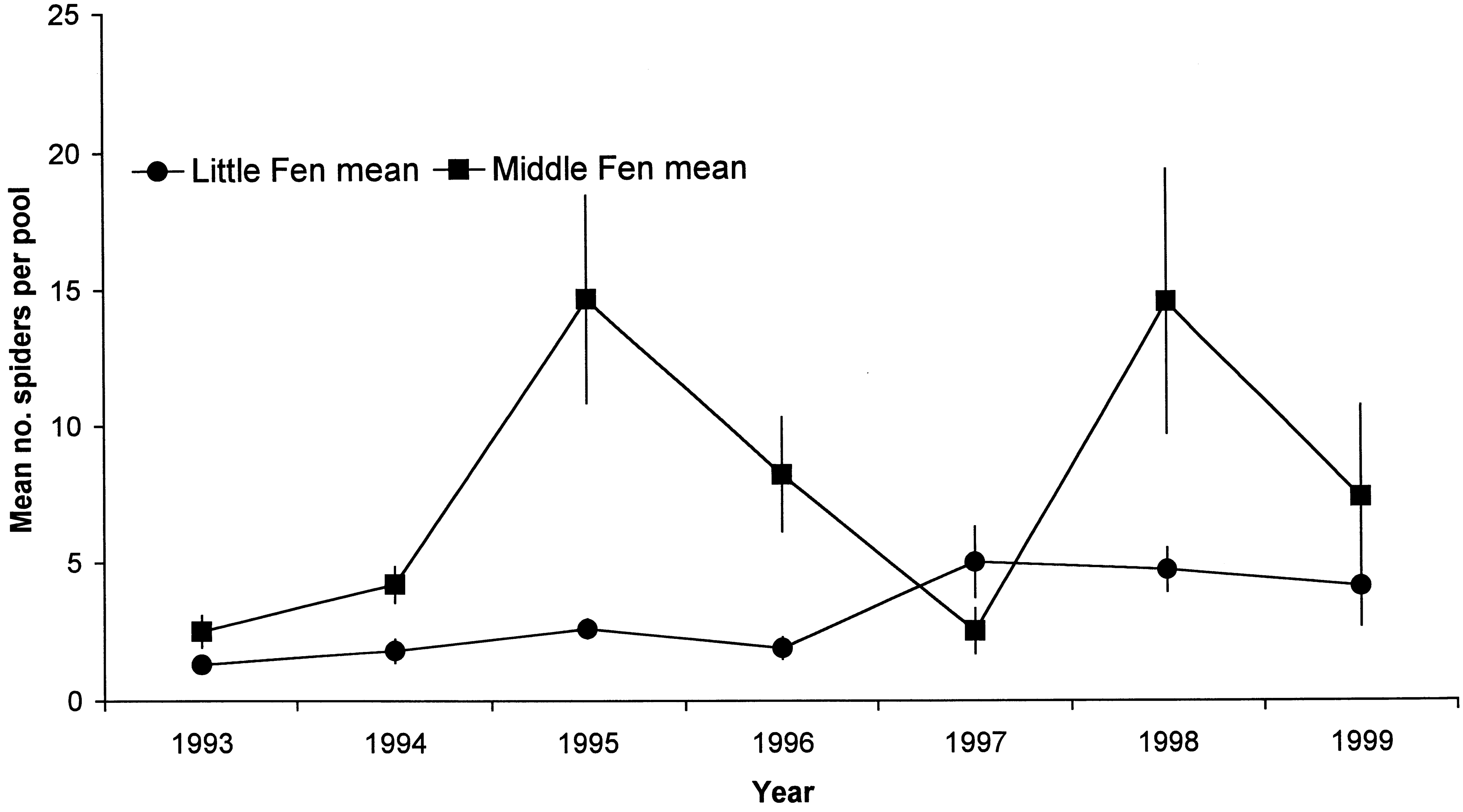


Figure 5 Mean numbers of spiders per occupied pool on Little and Middle Fen