The ecology of pike: aspects of population biology and movement of pike (Esox lucius L.) as determined by ultrasonic tracking in an artificial reservoir

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THE ECOLOGY OF PIKE: ASPECTS OF POPULATION BIOLOGY

AND MOVEMENT OF PIKE (ESOX LUCIUS L.) AS

dETERMINED BY ULTRASONIC TRACKING IN

AN ARTIFICIAL RESERVOIR.

BY

ROSALIND M. WRIGHT

Thesis submitted in fulfilment of the requirements
for the award of Master of Philosophy of the
Loughborough University of Technology.
February 1980.

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ABSTRACT.

The population of pike and their movements were studied in Staunton Harold Reservoir, Derbyshire. The length-frequency, length-weight relationship, relative condition, age and growth of pike were determined mainly from 85 pike caught by angling. The population of adult pike in the reservoir was estimated to be 430 with a biomass of 23 kg ha\(^{-1}\) and production of 4.01 kg ha\(^{-1}\).

3 mature females were equipped with externally attached ultrasonic transmitters, and tracked for up to 86 days from March to June 1979. The pike migrated from the main body of the reservoir when the water temperature rose to 7.5\(^{\circ}\)C, into its shallow arms covering distances of 1000-1500m in 24 hours. Spawning occurred mainly in late April and early May on substrata of silt, tree leaves and tree debris. The sonic tagged pike moved on and off the spawning grounds several times over a period of 12-19 days. Following spawning movement was extensive and by the end of May the 3 pike occupied restricted areas or home ranges of 8.69 - 10.27 ha., mainly in depths of less than 10m. As June progressed the pike were more frequently found in depths less than 3m in beds of vegetation. 24 hour surveys revealed circadian rhythms which showed little nocturnal movement. The main activity peaks were at dawn, midmorning and dusk, and these corresponded to the times of most successful angling, therefore movement may be associated with feeding.
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CHAPTER 2

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ACKNOWLEDGEMENTS.

I would like to thank my supervisor, Mr. Gerry White for his support and help with field work and Dr. E. Hamley for his advice during the preparation of this thesis. I also thank the anglers who caught pike, especially Mr. M. McGowan who also helped with field work and electronic instrumentation; Mr. T. Langford (CEGB) for all his advice on ultrasonic tracking techniques; the Water Research Centre, Stevenage for the loan of equipment; Mr. A. Tassopoulos for help with the computing; all those who gave assistance with field work and finally to the Severn Trent Water Authority for permission to do this project at Staunton Harold Reservoir.

My special thanks to my mother, Mrs. B. Wright for all her encouragement and support and for typing this thesis.
GENERAL INTRODUCTION.

Pike are found in lakes and slow-flowing rivers in temperate Europe, Asia and North America. Although widespread, only one genus exists with five species. One species, *Esox lucius*, the Northern pike occurs in Europe.

Classification.

<table>
<thead>
<tr>
<th>Sub Phylum</th>
<th>Vertebrata</th>
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</thead>
<tbody>
<tr>
<td>Class</td>
<td>Osteichthyes</td>
</tr>
<tr>
<td>Order</td>
<td>Haplomi</td>
</tr>
<tr>
<td>Family</td>
<td>Esocidae</td>
</tr>
<tr>
<td>Genus</td>
<td>Esox</td>
</tr>
<tr>
<td>Species</td>
<td>Lucius</td>
</tr>
</tbody>
</table>

Pike are the predominant predators in freshwater and feed almost entirely on fish. Growth is variable with ultimate lengths ranging from 30 – 120 cm. (Maitland 1977). Berg (1962) recorded a record weight of 34 kg, but the rod record for Great Britain is 18 kg although claims for weights up to 32 kg have been made.

Pike are of considerable commercial importance in continental Europe and in North America. They have been used as a predator in polyculture schemes in fish farming. (Bardach et al. 1972), and are a popular food fish. However, the main interest in pike is as a sport fish for which they are greatly valued in North America and Europe. Esocids are cultured intensively in North America to provide recreational fishing and as a management tool.
for control of stunted or undesirable fish. (Graff 1978).

However, there is some doubt as to whether introduction of pike fry into water already inhabited improves fishing. (Svardson 1949).

Interest in pike in Britain is growing, indicated by the increasing number of members of the Pike Anglers Club (PAC) and the National Association of Specimen Groups (NASG). These organizations have realized the need for conservation of large pike and advocate the returning of pike to water after capture. Unfortunately not all anglers share this view, and many pike are indiscriminately killed. Overfishing and culling of large pike changes the age structure and growth rate of the pike population (Kipling and Frost 1970, Frost and Kipling 1972, Otto 1979). Three phases have been identified:

1) a high proportion of large fish,
2) a high proportion of small fish and
3) equal numbers of large and small fish.

Removal of large pike reduces cannibalism and results in a better survival of small pike. Kipling and Frost (1970) did not find any correlation between year class strength and numbers of parents or biomass of mature females. Therefore, as large numbers of small pike are not desirable in a fishery, large pike should be preserved.

The role of predacious fish in mixed fish communities is multipurpose. Pike influence the quantitative and qualitative composition of prey species. Frost (1954) used stomach content analyses and showed that species of fish eaten appeared to be related to abundance and availability rather than selection by
the pike. Therefore, by regulating the abundance of other prey species as well as themselves, predators enhance the stability of an ecosystem. They may also be regarded as biological meliorators as they eliminate sick, weak and abnormal individuals; i.e. the part of the population that would die first in unfavourable conditions. In this manner, they increase the food supply and feeding condition for the rest of the fish and promote an increase of the rate of adaptation of prey species to the influence of stress factors which is particularly important in modern pollution conditions. (Popova 1978).

As the pike is the predominant predator in British freshwaters, more information is needed about its ecology and behaviour to contribute to the assessment of the role of pike in ecosystems, as a sport fish, and for future conservation and coarse fish management.

AIMS.

The purpose of this study was to investigate:

1) The length-weight relationship, relative condition, age and growth of pike.

2) The population structure, density, biomass and production of pike in an artificial reservoir used for recreational fishing.

3) The distribution and habitat preference of pike prior to, during and after spawning.

4) The movements of pike over the spawning period, and the characteristics of the spawning grounds.
5) The post spawning dispersion and possible establishment of home ranges.

6) Daily movements and diurnal or nocturnal rhythms of pike.

7) The role of fish location systems in fisheries management.

THE SITE.

The pike population studied was in Staunton Harold Reservoir, Melbourne, Derbyshire. [National Grid Reference SK3723], (Fig. 1). The main water intake is from the River Dove and in addition there are four tributary brooks which all pass through fish ponds, quarries or artificial enlargements before entering the reservoir. These provide silt traps. The top water level is at 245 ft (75 m) AOD and the maximum depth is about 25 m. The water surface area is 209 acres (84.6 ha) and the reservoir has a capacity of 1400 million gallons (6,364,400 m³).

The pH value ranged from 7.70 to 8.30. Ice covered the reservoir from 11 January - 13 February. Water temperatures and pH values for 1979 are given in Appendix 1.

Macrophytes were not abundant and those present in October, 1979 are listed in Appendix 2.

The fish population consists mainly of pike (Esox lucius L), perch (Perca fluviatilis L), roach (Rutilus rutilus L), bream (Abramis brama L), and tench (Tinca tinca L).

The reservoir is for storage of freshwater, and the recreative uses are sailing and angling from restricted banks. The southern arms are a nature reserve, administered by the Derbyshire Naturalists' Trust.
FIG. 1.
Map of Staunton Harold Reservoir with British Isles inset.

- Fishing Area.
- *1-9 Sailing Club buoys.
- Woodland.

Scale: 500m

Inset: Staunton Harold Reservoir
CHAPTER 1

THE LENGTH-WEIGHT RELATIONSHIP, RELATIVE CONDITION, AGE AND GROWTH, POPULATION AND BIOMASS OF PIKE IN STAUNTON HAROLD RESERVOIR.
INTRODUCTION.

There are relatively few studies on the ecology of pike in the British Isles. In stillwater habitats, information is available on the pike in Windermere (Frost and Kipling 1967, Kipling and Frost 1970), Loch Lomond and Dubh Lochan (Shafi and Maitland 1971), Loch Choin (Munro 1957), Rostherne Mere (Banks 1970), L. Sillon (Bracken and Champ 1971) and Lough Glore (Healey 1956). In running waters there are accounts on pike in the Rivers Stour and Frome in southern England, (Mann 1976) and four Irish trout rivers (Bracken 1973).

As growth rate is extremely variable, a pike population may be considered slow, average, fast and exceptional growing. It is a well established fact that females have faster growth rates than males, and where comparison is made between populations in different localities, the female growth rates have generally been used.

In this chapter the length-weight relationship, relative condition, age and growth, population and biomass of pike in an artificial reservoir is determined and compared where possible to pike in other waters.

* Frost and Kipling 1967
MATERIALS AND METHODS.

Of the methods available to yield live fish, the most productive was found to be angling (Plate 1). 90 pike were caught by this method from March to June. A further six were caught in perch traps during April - May. Seine netting was not successful during these months. The length frequencies of pike caught (Fig. 2) show that angling is size selective and fish caught ranged from 55 cm to 101 cm, but for this study the main interest is in the adult fish.

The pike were weighed, measured (fork length) and sexed when possible, mainly prior to and just after spawning.

A 1 cm numbered monel metal strap tag was applied to the opercular bone (Plate 2) by means of a pair of applicators. A small hole was drilled through the bone by a battery operated hand drill (RS Components, printed circuit board drill) so the tag could be fixed through the bone easily. Initially tags were placed on the soft tissue above the opercular bone but this was unsatisfactory as tags were lost after about a month.

3-4 scales for ageing were taken from an area above the lateral line and about midway along the body length using a pair of fine serrated forceps. These scales are more typical in form and larger in size than from other parts of the body. (Frost and Kipling 1959). The scales were taken with care and selected so as to avoid taking 'replacement scales' which are useless for ageing.

Back calculation of growth was determined from opercular bones, as there are difficulties in using scales (Frost and Kipling 1959). It is necessary to kill the fish to remove opercular bones and it was hoped to keep mortalities to the minimum. Therefore, opercular
bones were only removed from diseased or damaged pike, and those found dead round the margins during the spawning period.

Distinguishing features, deformities and the presence of ectoparasites on the pike were noted.

For all photographs a 35mm SLR camera was used, equipped with a 50mm F1.8 lens. The film was Kodacolor II (ASA 100/21 DIN).
Plate 1. Female pike caught by angling before spawning.

Plate 2. A. A numbered strap tag fixed to the opercular bone of the pike.  
B. *Piscicola geometra*, a common ectoparasite of pike.
Fig. 2. Length-Frequency distribution of Staunton Harold pike caught by angling and perch traps.
A. LENGTH WEIGHT RELATIONSHIP AND RELATIVE CONDITION.

1. Length-Weight Relationship.

The lengths of male and female pike when plotted against weights on an arithmetic scale gives a curve (Fig. 3a). When transferred to a log-log relationship, a straight line is obtained (Fig. 3b).

The length weight relationship was calculated using the formula:

\[ W = a L^b \quad (1) \]

which in logarithmic form becomes:

\[ \log W = \log a + b \log L \quad (2) \]

where \( W \) = weight in kg,
\( L \) = length in cm,
\( a \) and \( b \) are constants.

The values of \( \log a \) and \( b \) were computed from the following equations given by Beckman (1945). (Appendix 3).

\[ \log a = \frac{\Sigma \log W \cdot \Sigma (\log L)^2 - \Sigma \log L \cdot \Sigma \log L \cdot \Sigma \log W}{N \Sigma (\log L)^2 - (\Sigma \log L)^2} \quad (3) \]

\[ b = \frac{\Sigma \log W - N \log a}{\Sigma \log L} \quad (4) \]

where \( W \) and \( L \) are as defined above, and
\( N \) = the number of fish.

Solutions of equations (3) and (4) for prespawning, post spawning, and the total sample of pike are given in Table 1.
Fig. 3. The weight-length relationship of pike;
   a) Weight against length, on arithmetic scale.
   b) Weight against length, on logarithmic scale.
TABLE 1.

Length-Weight regression coefficients of Staunton Harold Reservoir pike calculated from \[ \log W = \log a + b \log L \] where \( W \) = wt of fish (kg) and \( L \) = fork length (cm).

<table>
<thead>
<tr>
<th></th>
<th>No. of fish</th>
<th>( \log a )</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (Feb + April)</td>
<td>34</td>
<td>-4.393</td>
<td>2.676</td>
</tr>
<tr>
<td>Females and Males (April + June)</td>
<td>62</td>
<td>-5.181</td>
<td>3.056</td>
</tr>
<tr>
<td>Females and Males (Feb + June)</td>
<td>96</td>
<td>-5.228</td>
<td>3.094</td>
</tr>
</tbody>
</table>

Using the regression coefficients the expected weight for a given length may be calculated from equation (2).

The values of \( \log a \) for the prespawning and postspawning pike are different at all levels of significance.

For post spawning fish and the total sample of pike, \( b \) is not significantly different from 3. However for prespawning pike at a significance level of 0.05, \( b \) is just different to 3.

The regression coefficients calculated for pike in other waters show the length-weight relationship to be very similar. (Table 2).
TABLE 2.

Length-weight regression coefficients of pike from various waters.
(Conversions to units of kg made when necessary)

<table>
<thead>
<tr>
<th></th>
<th>log a</th>
<th>b</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Stour Immat.</td>
<td>-5.11</td>
<td>3.00</td>
<td>Mann 1976.</td>
</tr>
<tr>
<td>Females</td>
<td>-5.23</td>
<td>3.05</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>-5.03</td>
<td>2.97</td>
<td></td>
</tr>
<tr>
<td>Females (Summer)</td>
<td>-5.59</td>
<td>3.27</td>
<td></td>
</tr>
<tr>
<td>(Jan.)</td>
<td>-5.39</td>
<td>3.22</td>
<td></td>
</tr>
<tr>
<td>Males (Summer)</td>
<td>-5.44</td>
<td>3.18</td>
<td></td>
</tr>
<tr>
<td>(Winter)</td>
<td>-5.36</td>
<td>3.17</td>
<td></td>
</tr>
<tr>
<td>Imm.</td>
<td>-5.28</td>
<td>3.09</td>
<td></td>
</tr>
<tr>
<td>Loch Lomond.</td>
<td>-5.2196</td>
<td>3.147</td>
<td>Shafi and Maitland 1971.</td>
</tr>
<tr>
<td>Females</td>
<td>-5.6141</td>
<td>3.295</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lochan Dubh.</td>
<td>-5.6566</td>
<td>3.35</td>
<td>Shafi and Maitland 1971.</td>
</tr>
<tr>
<td>Females</td>
<td>-5.4464</td>
<td>3.24</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loch Choin.</td>
<td>5.3293</td>
<td>3.08</td>
<td>Munro 1957.</td>
</tr>
</tbody>
</table>
2. Relative Condition.

The relative condition (kn) of individual pike was calculated by the method described by Le Cren (1951).

\[ \text{kn} = \frac{W_0}{\hat{W}} \]

where \( W_0 \) = observed weight,
and \( \hat{W} \) = expected weight.

Values of \( \hat{W} \) are derived from the regression coefficients for the total number of fish \( \log W = -5.228 + 3.094 \log L \), so the relative condition of prespawning and post spawning fish may be compared. (Table 3).

**TABLE 3.**
Relative condition factors of Staunton Harold pike calculated from \( \text{kn} = \frac{W_0}{\hat{W}} \).

<table>
<thead>
<tr>
<th></th>
<th>No. of Fish</th>
<th>Average kn</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prespawning Pike</td>
<td>34</td>
<td>1.100</td>
<td>0.914 - 1.381</td>
</tr>
<tr>
<td>(March)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postspawning Pike</td>
<td>62</td>
<td>0.958</td>
<td>0.735 - 1.416</td>
</tr>
<tr>
<td>(May - June)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pike</td>
<td>96</td>
<td>1.010</td>
<td>0.735 - 1.416</td>
</tr>
<tr>
<td>(March - June)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
B. AGE AND GROWTH.

1. Determination of Age.

Scales may be used for determining the age of pike (Williams 1955) but are not recommended for estimating growth (Frost and Kipling 1959). The annuli on the anterior parts of the scale were used for ageing as the posterior part becomes confused in older fish.

The scales were washed with warm water, mounted between two microscope slides and examined under a Gakken Macro-Vu GMR 230 projector at 16x magnification.

Age-length data is given in Fig. 4a. There is a wide range of lengths for age, and according to scale readings most of the fish caught were between 6 and 10 years old.

The catch curve is shown in Fig. 4b.

The frequency curve peaked at 8 years and 30% of pike caught were of this age.

2. Back Calculations from Opercular Bones.

Back calculated lengths at earlier ages were determined from opercular bones. Frost and Kipling (1959) recommend that the opercular bone be used for estimating age and growth as although scales are satisfactory for determination of age, they present certain difficulties and inaccuracies in back calculations of growth from annuli.

The opercular bones were removed and soaked in hot water for a few minutes and then cleaned with tissues and stored in an envelope with details of the pike from which they were obtained.
For examination the opercular bones were rinsed in xylol and observed at 5x magnification using a Durst J 66 enlarger. A strip of cardboard was laid on the image and the position of the rings marked off. The edge of the strip is set at right angles to the line used in locating the centre of the bone. (Frost and Kipling 1959).

Back calculations of growth can be made by direct proportion. The marked strips of card were laid on a piece of graph paper with the expected range of fish lengths marked on the y axis. With the zero of the bone measurements at the origin, the strip is rotated until the opercular bone edge mark is opposite the observed fish length. The back-calculated lengths corresponding to each annulus were read directly from the y axis. (Bagenal and Tesch, 1978).

The results of the back calculations are given in Table 4.
Fig. 4. (a) Age/Length Data from scale readings and actual lengths of pike in Staunton Harold Reservoir.
(b) Catch curve.
**TABLE 4.**

Mean Back Calculated lengths (cm) for age of male and female pike of Staunton Harold Reservoir.

<table>
<thead>
<tr>
<th>SEX</th>
<th>No. of Fish.</th>
<th>LENGTH AT AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>MALE</td>
<td>5</td>
<td>20.5</td>
</tr>
<tr>
<td>FEMALE</td>
<td>7</td>
<td>23.5</td>
</tr>
<tr>
<td>MALE &amp; FEMALE</td>
<td>12</td>
<td>23</td>
</tr>
</tbody>
</table>
3. **Growth.**

**a) Length.**

Mean lengths for age of male and female pike obtained from back calculation methods (Table 4) were plotted on a graph (Fig. 5) so growth may be compared to male and female pike in Lake Windermere. (Frost and Kipling 1967). In Fig. 6 growth of Staunton Harold pike is compared to growth of pike from various waters in the British Isles.

**b) Weight.**

Length weight regression coefficients were used to convert the mean lengths in Table 4 to mean weights. The results are given in Table 5.

Instantaneous growth rates (IGR) were calculated from:

\[
IGR = \log_e \left( \frac{W_{t+1}}{W_t} \right)
\]

where\[W_t = \text{weight at } t\]

\[W_{t+1} = \text{weight at } t + 1\text{y.}\]
Fig. 5. Growth of male and female pike from Staunton Harold Reservoir and Lake Windermere, 1946-47 (Frost & Kipling 1959).
Fig. 6. Growth of pike from various waters in the British Isles.

Data from Lough Glore (Healey 1956); River Stour (Mann 1976), Staunton Harold Reservoir; Loch Choin (Munro 1957), Lochan Dubh (Shafi & Maitland 1971).
TABLE 5.

Mean weights and instantaneous growth rates (IGR) of male and female pike.

<table>
<thead>
<tr>
<th>AGE (y)</th>
<th>MALE</th>
<th>FEMALE</th>
<th>MALE &amp; FEMALE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Wt. (kg)</td>
<td>IGR</td>
<td>Mean Wt. (kg)</td>
</tr>
<tr>
<td>0</td>
<td>0.0001</td>
<td>6.5</td>
<td>0.0001</td>
</tr>
<tr>
<td>1</td>
<td>0.067</td>
<td>1.482</td>
<td>0.103</td>
</tr>
<tr>
<td>2</td>
<td>0.295</td>
<td>0.673</td>
<td>0.339</td>
</tr>
<tr>
<td>3</td>
<td>0.578</td>
<td>0.075</td>
<td>0.825</td>
</tr>
<tr>
<td>4</td>
<td>0.623</td>
<td>0.476</td>
<td>1.355</td>
</tr>
<tr>
<td>5</td>
<td>1.003</td>
<td>0.214</td>
<td>1.976</td>
</tr>
<tr>
<td>6</td>
<td>1.242</td>
<td>2.642</td>
<td>0.223</td>
</tr>
<tr>
<td>7</td>
<td>3.301</td>
<td>0.248</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4.228</td>
<td>0.192</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5.124</td>
<td>0.0737</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5.516</td>
<td>0.177</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>6.583</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
c) **Ford-Walford Plots.**

Ford-Walford plots were constructed (Ford 1933, Walford 1946) for male and female pike (Fig. 7). Mean back calculated lengths (Table 4) were used and the straight lines fitted by computer using the method of least squares (Appendix 3). This technique is a graphical transformation of the Von Bertalanffy equation which describes growth by two parameters \( L_\infty \), the ultimate length, and \( k \), the rate (slope) at which the ultimate length is approached. (Von Bertalanffy 1957). \( L_\infty \) is affected by the food supply and population density, while \( k \) is affected by genetical and physiological factors. (Beverton and Holt 1957).

The slope (\( k \)) may be used to determine the coefficients of anabolism (\( E \)) and catabolism (\( K \)):

\[
K = -\log_e k,
\]
\[
E = K L_\infty ,
\]

where \( k \) is the slope of the lines in Fig. 7, and \( L_\infty \) (ultimate length) is the intercept with the 45° slope.

The results are given in Table 6, together with results from Windermere (Frost and Kipling 1967), Lough Clore (Healey 1956) and the River Stour (Mann 1976).
Fig. 7. Walford plots for male and female pike. Ultimate lengths ($L_\infty$) were obtained from the intercepts with the $45^\circ$ slope lines, and $k$ values represent the slopes of the Walford plots.
TABLE 6.

Estimates of ultimate length ($L_\infty$) and von Bertalanffy coefficients $K$ and $E$ of pike from Staunton Harold Reservoir, River Stour (Mann 1976), Windermere (Frost and Kipling 1967) and Lough Glore (Healey 1956).

<table>
<thead>
<tr>
<th></th>
<th>$L_\infty$</th>
<th>$K$</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staunton Harold Reservoir.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varphi$</td>
<td>98</td>
<td>.22</td>
<td>21.7</td>
</tr>
<tr>
<td>$\delta$</td>
<td>55</td>
<td>.46</td>
<td>25.3</td>
</tr>
<tr>
<td>River Stour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varphi$</td>
<td>100</td>
<td>.24</td>
<td>24.0</td>
</tr>
<tr>
<td>$\delta$</td>
<td>77</td>
<td>.25</td>
<td>23.1</td>
</tr>
<tr>
<td>Windermere (1951-55)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varphi$</td>
<td>116</td>
<td>.28</td>
<td>22.0</td>
</tr>
<tr>
<td>$\delta$</td>
<td>77</td>
<td>.36</td>
<td>27.6</td>
</tr>
<tr>
<td>Lough Glore</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta \varphi$</td>
<td>141</td>
<td>.16</td>
<td>22.6</td>
</tr>
</tbody>
</table>
C. ESTIMATION OF POPULATION.

The population of pike over 55 cm was estimated by a mark-recapture method. 89 fish were caught by rod and line over a period of 4 months, and tagged. Of this number 19 fish were recaptures. One fish was caught twice on the same day, and this was excluded from the calculation as random distribution may not have occurred. As the fish were sampled by catching one fish, tagging and then returning to the water, for the purposes of the calculation, the number of marked fish was considered equal to a sample. The estimation formula was that used by the Petersen method. (Youngs and Robson 1978).

\[ \hat{N} = \frac{mc}{r} \]

where \( \hat{N} \) = number of fish in population.
\( m = \) number of marked fish in population.
\( c = \) number of fish in sample.
\( r = \) number of marked fish in c.

Then \[ \hat{N} = \frac{88 \times 88}{18} \]
\[ \hat{N} = 430.22 \]

The estimated population number of pike over 55 cm is 430, which is 5.1 fish ha\(^{-1}\).

The variance of \( \hat{N} \) is calculated by:

\[ \hat{V}(N) = \frac{m^2c(c-r)}{r^3} \]

and the results are given in Table 8.
D. ESTIMATION OF BIOMASS, MORTALITY AND PRODUCTION.

1. Biomass.

The biomass \( B \) of adult pike (55 cm +) was estimated by multiplying the mean weight of pike caught from April to June and multiplying this by the population number. (Chapman 1978).

\[
B = \bar{W} \times \hat{N}
\]

where \( \bar{W} \) = mean weight, and \( \hat{N} \) = estimated population number.

Then \( B = 4.5 \times 430.22 \)

\( B = 1936 \) kg.

Biomass is estimated as \( 1936 \) kg which is \( 23.7 \) kg ha\(^{-1}\).

2. Exponential models of growth and mortality.

When growth is considered to be exponential, its instantaneous coefficient \( G \) is estimated by:

\[
G = \frac{\log_e \bar{W}_2 - \log_e \bar{W}_1}{\Delta t}
\]

where \( \bar{W}_1, \bar{W}_2 \) = mean weights of fish at times \( t_1 \) and \( t_2 \) respectively.

In this case values used are for pike from 6 to 11 years old, as these were the ages of most of the fish caught.

\[
\log_e 6.583 - \log_e 2.405
\]

Then

\[
G = \frac{\log_e 6.583 - \log_e 2.405}{5}
\]

\( G = 0.20 \).

Similarly if population decrease is exponential, the instantaneous coefficient of mortality \( Z \) is:
\[ Z = \frac{-\left(\log_e N_2 - \log_e N_1\right)}{\Delta t} \]  

(3)

where \( N_1 \) and \( N_2 \) = numbers of fish present at times \( t_1 \) and \( t_2 \), respectively.

Then

\[ -(\log_e 9 - \log_e 23) \]

\[ Z = \frac{2}{2} \]

\[ Z = 0.47 \]

As \( G < Z \) it may be assumed that the stock is decreasing exponentially. The average biomass \( \bar{B} \) is calculated by:

\[ \bar{B} = \frac{B\left(1 - \exp\left[-(Z-G)\Delta t\right]\right)}{(Z-G)\Delta t} \]  

(4)

where

- \( B \) = biomass calculated in (1).
- \( Z \) = instantaneous coefficient of mortality calculation in (3).
- \( G \) = instantaneous coefficient of growth calculation in (2).
- \( \Delta t \) = time interval of 1 year.

Then

\[ \bar{B} = \frac{1936 \left(1 - \exp\left[.27\right]\right)}{.27} \]

\[ \bar{B} = 1696.66 \text{ kg.} \]

3. **Production.**

Production is a basic parameter in population dynamics, linking population density, growth rate and survival rate. Freshwater fish production has been estimated from a variety of waters and ranges from less than 1 kg.ha\(^{-1}\) to 60 kg.ha\(^{-1}\), and depends on the basic productivity of the waters. (Le Cren 1972). Kipling and Frost (1970) estimated production of pike in Lake Windermere to be 2.36 to 6.76 kg.ha\(^{-1}\). For comparison production of pike in Staunton Harold Reservoir was estimated.
Ricker (1946) and Allen (1950) formulated production during a period of $\Delta t$ as:

$$ P = G \Delta t \bar{B} \quad (5) $$

where $G =$ instantaneous coefficient of growth calculated in (2).

$\Delta t =$ time interval of 1 year.

$\bar{B} =$ mean biomass calculated in (4).

Then

$$ P = 0.20 \times 1 \times 1696.66 $$

$$ P = 339.33 \text{ kg.} $$

Production of pike in Staunton Harold Reservoir is 339.33 kg, which is 4.01 kg ha$^{-1}$. However, this is underestimated as the calculation excludes the younger age class and reproductive products, but suggests that productivity in Staunton Harold Reservoir would be higher than in Lake Windermere.


The results are given in Table 8.
TABLE 8.

Estimates, Variance, Standard Deviation (SD) and 95% confidence levels of the population, biomass and production of adult pike in Staunton Harold Reservoir.

<table>
<thead>
<tr>
<th></th>
<th>ESTIMATE</th>
<th>VARIANCE</th>
<th>SD.</th>
<th>95% CONFIDENCE LEVELS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>POPULATION</td>
<td>430</td>
<td>8179.5</td>
<td>90.4</td>
<td>251 - 609</td>
</tr>
<tr>
<td>NO. FISH/HA</td>
<td>5.1</td>
<td>1.18</td>
<td>1.08</td>
<td>3 - 7.2</td>
</tr>
<tr>
<td>BIOMASS</td>
<td>1936</td>
<td>174009</td>
<td>417</td>
<td>1102 - 2769</td>
</tr>
<tr>
<td>BIOMASS/HA</td>
<td>23</td>
<td>25.1</td>
<td>5.01</td>
<td>13 - 33</td>
</tr>
<tr>
<td>PRODUCTION</td>
<td>339.3</td>
<td>11653</td>
<td>108</td>
<td>123 - 447</td>
</tr>
<tr>
<td>PRODUCTION/HA</td>
<td>4.01</td>
<td>1.034</td>
<td>1.02</td>
<td>2.1 - 6.03</td>
</tr>
</tbody>
</table>
DISCUSSION.

The most successful method of catching pike during March – June was angling. The pike suffered little damage during capture, and angling proved to be the only practical way of the means available of catching fish and returning them live to the water. Most of those caught were between 65 and 92 cm. The smallest size caught by angling was 55 cm.

One reason for the size selectivity of angling was thought to be the size of the bait used. With increasing predator size, the range of prey sizes also increases. However, the average curve for size of prey lies closest to a curve of the minimum prey size. Popova (1978) found that the average size of prey for pike over 20 cm in the Volga delta was 8 cm. Most of the baits used in this study were 8 – 10 cm fish, and therefore, it does not seem likely that size of bait was the reason for the lower limit of size of pike caught by angling. Most of the baits used were deadbaits. The diet of larger pike may include more dead fish which makes them more susceptible to being caught by this method of angling.

Most of the pike caught by angling were female. Female pike have a higher growth rate than males and seem to live longer, therefore as anglers appeared to be selectively catching large pike, it was expected that most would be female. However, angling occurred during March, May and June but not in April during spawning. Otto (1979) found that females dominated catches from May to August, but more males than females were caught during spawning in April. Therefore, it may have been that angling was selective for females
during these months, rather than size selective as was previously thought.

The relative condition of female pike after spawning is low. The gonad weight comprises about 15 - 20% of the total body weight, compared with 2 - 4% in male pike. (Frost and Kipling 1967). This may account for the increased feeding rate of pike in May, and the females' susceptibility to angling indicates a high food demand after egg formation and spawning. Popova (1978) found that daily rations of pike were highest in the Volga delta during May rising to 6% of body weight.

Other factors contributing to low condition included anglers' damage and imbedded residual hooks, parasites and old age.

From the length-weight regression coefficient calculated from \( \log W = \log a + b \log L \), \( b = 3.09 \). If growth is isometric, \( b = 3 \). (Bagenal and Tesch 1978). Therefore growth of mature pike in Staunton Harold Reservoir is isometric. However \( b \) may have differed significantly to 3 if the younger age classes had been included in the sample. By comparing pike in various waters, Staunton Harold pike show greater weights for lengths than pike in the River Stour (Mann 1976), Windermere (Frost and Kipling 1967) and Loch Choin (Munro 1957).

Most of the pike caught were between 6 and 10 years old according to scale readings. The minimum age of pike caught by angling was 5 years, and the maximum age was 11 years. However, scales may be considered as a record of the growth of the fish as an annulus is formed during winter when growth is checked. (Frost and Kipling 1959). In older fish the annuli are so close
together they are difficult to count. Scale readings therefore, may indicate the age at which growth has ceased or is very slow, so it is possible that the actual age of the pike is older. Miller and Kennedy (1948) thought that the duration of life in the pike appears to depend, at least to some extent, upon growth rate and found that the growth rate decreased with increasing latitude and that this decrease was associated with an increase in the length of life.

There is a wide variation of lengths for age, 11 years of age or alternatively 11 years of growth is average for pike in Great Britain.

Age may have been underestimated in pike over 8 years old because of the difficulties in counting annuli which are extremely close together. In some cases there were difficulties in identifying false annuli, and consequently age may have been overestimated. However, scale readings were confirmed by a number of workers experienced in ageing by scales, and agreement was generally within ± one year.

There is a wide variation of lengths for age of pike. Growth of females is faster than males. There is also individual variation in growth rates, and a pike may be considered fast, average or slow growing within its own year class. There is also variation between year classes and year class strengths and growth is significantly correlated with temperature conditions (Frost and Kipling 1967, Kipling and Frost 1970). Casselman (1978) found growth was optimal at 19 – 21°C. Such differences in growth rate indicate that pike have great capacity to acclimatize to changes
in the environmental conditions.

The minimum age according to scale readings of the pike caught by angling was 5 years. As there are difficulties in making calculations from scales, opercular bones were used for back calculations, so growth of pike in Staunton Harold Reservoir could be compared to pike in other waters. The back calculations were mainly from pike over 65 cm, and the mean lengths for age showed Lee's phenomenon. (Lee 1912). Frost and Kipling (1959) attributed the presence of Lee's phenomenon in their data to gillnet selection. Mann (1976) caught pike by electrofishing, gillnets, angling and traps which reduced size selectivity, and this is reflected by the absence of Lee's phenomenon.

Growth of Staunton Harold pike may be considered average in comparison to pike in other waters in the British Isles, and is similar to growth of pike in the River Stour (Mann 1976), Windermere (Frost and Kipling 1967) and Loch Lomond (Shafi and Maitland 1971). The pike in Lough Glore (Healey 1956) and the River Frome (Mann 1976) are fast growing. Slow growth occurs in Loch Choin (Munro 1957), Lochan Dubh (Shafi and Maitland 1971) and also Rostherne Mere (Banks 1970).

The ultimate lengths of male and female pike found by Ford Walford plots are underestimated. One reason may be the presence of Lee's phenomenon. \( L_\infty \) for females was found to be 98 cm and 4 fish above this length were caught. The greatest recorded length was 101 cm. \( L_\infty \) for males was 55 cm. The sample for males was small, and 8 fish were caught above this length. The maximum was 69 cm. An ultimate length of 75 cm for male pike and 100 cm
for female pike would be comparable to Lake Windermere where growth rates were similar (Frost and Kipling 1967).

Tag recaptures indicated an adult pike population (55 - 101 cm) of 430. The average density of pike in the reservoir is 5.2 fish ha\(^{-1}\). However, this does not take into account habitat preferences, where density of pike may be far higher, and areas where no pike are located. One purpose of Chapter 2 is to determine the distribution and habitat preference of pike in a reservoir. In Windermere, Kipling and Frost (1970) calculated the maximum density of pike aged 2+ and over in areas shallower than 10 metres to be 8.3 fish ha\(^{-1}\). From figures given by Munro (1957), the density of pike aged 2+ was 7.9 fish ha\(^{-1}\) in Loch Choin. In Lochan Dubh (Shafi and Maitland 1967) density of pike was found to be 8.9 adult fish ha\(^{-1}\).

The high proportion of pike in the 6 - 10 years old age group, indicates that mortality of large pike in Staunton Harold Reservoir is relatively low. Fishing for pike is from restricted banks only and from 1 October to 14 March. Pollution is not a serious problem as the water is a freshwater reservoir, and natural predation is low for pike over 55 cm. Juvenile survival of pike is consequently low, and this was confirmed by the comparatively few smaller pike caught by angling and in perch traps. Therefore, it may be concluded that the population composition at present in Staunton Harold Reservoir is similar to Lake Windermere (Kipling and Frost 1970), and in Västra sjö, an oligotrophic lake in southern Sweden (Otto 1979), before
overfishing caused changes in their population structures.

Biomass and production in Staunton Harold Reservoir are relatively high. The factors affecting production are population numbers, density, rates of growth, mortality, recruitment and migration. (Le Cren 1972). The production estimate of 4.01 kg. ha\(^{-1}\) in the reservoir is based mainly on pike over 55 cm, but these are thought to account for a large proportion of the biomass of pike. In natural freshwater, where fishing for pike occurs, the annual yield is 1 - 2 kg.ha\(^{-1}\). (Backiel 1971, Lind and Kaukoranta. 1975). Otto (1979) obtained a yield of 3.3 - 4.7 kg.ha\(^{-1}\) in five consecutive years which he considered a fair yield for pike, although changes in the population structure were brought about. Interest in pike in Britain is mainly for sport rather than food, and pike anglers are interested in catching specimen fish. Therefore yield is not of such importance as production, and prevention of overfishing in popular pike waters.

Conservation is becoming increasingly important. Therefore, a greater understanding of population dynamics and production is needed so that management of freshwater fisheries can take place to provide a long term yield that is optimum in biological and economic terms (Le Cren 1972).
CHAPTER 2

SPAWNING MOVEMENTS, HOME RANGES AND DIEL RHYTHMS OF PIKE AS DETERMINED BY ULTRASONIC TRACKING.
INTRODUCTION.

The utilization of available habitat by fish species is an important issue in fisheries management. There is little information available on location, density, territoriality, home range, and diurnal, seasonal and annual movement patterns of pike. Studies of movements have mostly been based on recaptures of tags (Moen & Henegar 1971, Miller 1948, Priegel 1968), numbers of pike caught in gillnets (Johnson 1960) and fyke nets (Priegel and Krohn 1975). However, movement between recaptures is unknown so a continuous record of locations cannot be made. Underwater biotelemetry provides a means by which fish movements can be continuously monitored.

Malinin (1969, 1970a, 1970b) and Diana et al (1977) have tracked pike using ultrasonic transmitters, but their evidence of whether pike occupy restricted areas or home ranges, or show transient movement is not conclusive. Crossman (1977) and Minor and Crossman (1978), using ultrasonic and radiotelemetry tracked another esocid, the Canadian muskellunge (*Esox masquinongy*), and found that the fish occupied summer and winter home ranges and travelled greater distances in spring when spawning occurs, and in the autumn.

The decision to use ultrasonic or radio transmitters is dependent on the environment (Stasko and Pincock 1977). For tracking pike in Staunton Harold Reservoir ultrasonic telemetry was used as more precise locations are possible. The main disadvantage of ultrasonics is attenuation of the signal because
of vegetation, algal blooms, turbulence and the difficulties caused by ice. However, the study was from March to June, and so these problems were not anticipated to be severe. The methods of utilization and information on ultrasonic techniques were gained from Stasko (1975), Stasko and Pincock (1977), Ireland and Kanwisher (1978) and Priede (1980).

Details of the reproduction of pike was obtained from Frost and Kipling (1967), Toner and Lawler (1969), June (1971), Priegel and Krohn (1975) and Mann (1976).
MATERIALS AND METHODS.

Equipment.

The system used was the commercially available Smith-Root equipment (Smith-Root Inc., Vancouver, Washington), consisting of sonic transmitters, hydrophone and receiver.

The transmitters (type SR69B) had an output frequency of 74 kHz ± 1 kHz with an expected life of approximately 45 days. They were 7 cm long, 14.5 mm in diameter and weighed 30 g in air prior to any treatment. Transmitters were identified by their individual pulse rates; the ones used had pulse rates of 0.97, 1.98, 2.4, 2.45, 3.89 and 5.4 pulses per second. Activation was by twisting the two external wires together which were sealed with silicone rubber which was allowed to set for 24 hours to ensure a water tight seal.

The hydrophone mainly used was the hand held model (SR70H) (Plate 5). The reception frequency range was approximately 25 – 88 kHz with the optimum sensitivity at 74 kHz, and a conical beam pattern of 8 degrees. The hydrophone had a 5 foot handle and a cable of 8 feet with a standard BNC connector installed for connection with the receiver.

Two omnidirectional Plessey hydrophones were also available, one of which was modified to make it directional (Stasko and Polar 1973), and they were used intermittently in conjunction with the Smith-Root hydrophone.

The sonic receiver (model TA-60) was designed for underwater ultrasonic tracking, and is tuneable to frequencies within the
range of 60 kHz to 180 kHz (Plate 6). The internal batteries are rechargeable and lasted for up to 24 hours tracking. Three sonic receivers were available, so time for recharging did not interrupt tracking periods. Two of the receivers were adapted to be recharged from 240 volt outlets, and the third from a 115 volt 50-60 cycle outlet. Low impedance headphones were used as these made detection of the audiosignals easier, particularly when the signal strength was weak.

A performance evaluation of this system was done by Summerfelt and Hart in 1971.

Transmitter attachment.

Three large female pike (73 – 90 cm) were caught by rod and line on March 28th 1979. Details concerning the length, weight, relative condition and transmitters attached to the pike are given in Table 9.

Smith-Root transmitters are designed for insertion into the stomach or for implanting in the peritoneal cavity. However, the pike is known to disgorge objects including transmitters from the stomach (Kendle and Morris 1965, Terry Langford, personal communication) and so this method was discarded. The alternative of surgical implantation in the body cavity has been successfully carried out on the muskellunge (Esox masquinongy) (Crossman 1977). The technique is described by Hart and Summerfelt (1975), but eventual loss of the transmitter is assumed. Therefore it was decided to attach the transmitter externally as the aim was to
recapture the pike and to change the transmitter with minimum stress so that the same fish could be tracked over an extended period of two transmitter battery lives, approximately 90 days.

A harness was devised to attach the transmitter to the fish. External harnesses for transmitter attachment have been used in other studies on a variety of species (Greer Walker et al. 1971, Tesch 1972, Young et al. 1972). Hallock et al. (1970) found that a transmitter fastened forward of the dorsal fin was the best position for external attachment. The methods used were not suitable for the present study as they did not permit easy interchange of transmitters. The requirements were a firm fit on the transmitter but flexible so it could slide in and out, and at the same time be attached securely to varying sizes of fish. After initial experiments with plastic, rubber proved to be the best material, and this was obtained from a bicycle inner tube.

A 1.5 cm strip was circumjacent the transmitter with two straps for attachment either side. Two lengths of surgical thread (0.5 mm diameter) were fastened by washers and crimps on one side ready for insertion through the dorsal muscle. The straps were double thickness so the crimps were enclosed inside. (Fig. 8).

The selected pike was removed from the keepnet and was held in an inverted position as this has a calming effect. Anaesthetic (1.10,000 MS222) was sprayed onto the gills. The harness with the activated transmitter inserted, was placed in position anterior to the dorsal fin. A long needled (7 cm) hypodermic syringe was
used to pierce through the muscle, the thread was passed through the bore of the needle and the syringe was withdrawn leaving the surgical thread in position. This was repeated for the second thread, and they were fastened off by washers and crimps on the opposite side which were then enclosed when the final stitches were made on the harness.

The harness was drawn to fit as closely as possible to the body of the fish to minimize drag which can affect swimming performance. (McCleave and Stred 1975). Another problem anticipated was abrasion at the points of entry of the surgical thread and it was hoped that a tightly drawn harness would avoid movement of the package and therefore prevent abrasion. A bactericide (1% potassium permanganate) was painted on the wounds to inhibit infection. (Plate 3).

After the operation the pike was placed in a large micromesh keepnet to recover from the anaesthetic and to make adjustments for its equilibrium and buoyancy to counteract the weight of the package. After approximately 30 minutes the transmitter signal was checked and the fish was released and monitored as it swam away. (Plate 4).
Fig. 8. External attachment of sonic tag to pike.
PLATE 3. Sonic tag and harness attached to pike F90.

PLATE 5. The directional hydrophone lowered from the side of the boat for ultrasonic tracking.

PLATE 6. The hydrophone is connected to the receiver which is set at 74 KHz. Headphones are used for detecting the signal.
Tracking.

Tracking was carried out from a Microplus 5 m cabin cruiser with a 20 HP outboard motor. (Plates 5 and 6). The hydrophone was lowered into the water and slowly rotated about 0.3 m below the surface. When a signal was detected, the boat moved slowly forward in the direction indicated by the hydrophone. Signal strength was inversely proportional to the distance from the fish, therefore with experience, approximations of the distance could be made, although this could vary with conditions. When the boat was over the position of the fish the signal achieved its maximum strength and the hydrophone relay was omnidirectional. The position of the fish was recorded on a map of the reservoir. Points around the reservoir and fixed sailing club buoys had been accurately surveyed and provided reference points when making locations.

If no signal was detected the boat stopped at intervals of about 200 m depending on the conditions, to check for signals. Over the spawning period the fish were located each day. Thereafter the fish were located on most days and tracking took place for varying intervals of time. Additionally, eight 24 hour tracking periods were conducted to establish diurnal and nocturnal rhythms.

Replacement of ultrasonic transmitter.

The Smith-Root transmitters were expected to last about 45 days on a single battery charge life (Summerfelt and Hart 1971), Water Research Council, personal communication). Towards the
end of this period each pike was located with the intention of recapturing the fish and replacing the sonic tag. Two fishing rods were used with a deadbait on one, and a livebait on the other. The baits were presented as near as possible to the sonic tagged pike.

When the pike was recought, the old transmitter was removed, and a replacement was inserted into the harness. Each pike was weighed, measured and checked if it had spawned. The condition of the harness attachment was noted. Each pike was held initially in a keepnet to check the new transmitter and then released, and a further tracking period for the life of the transmitters commenced.

The batteries in the expired transmitter were replaced by MA135 mercury cells. (Appendix 4).
### TABLE 9.

**INFORMATION ON THE PIKE FITTED WITH ULTRASONIC TRANSMITTERS.**

<table>
<thead>
<tr>
<th>PIKE</th>
<th>F73</th>
<th>F81</th>
<th>F90</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEX</td>
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<td>FEMALE</td>
<td>FEMALE</td>
</tr>
<tr>
<td>AGE</td>
<td>7</td>
<td>9</td>
<td>11</td>
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<tr>
<td>DATE OF CAPTURE</td>
<td>MARCH 28</td>
<td>MARCH 28</td>
<td>MARCH 28</td>
</tr>
<tr>
<td>SONIC TAG PULSE RATE</td>
<td>2.4</td>
<td>3.8</td>
<td>5.4</td>
</tr>
<tr>
<td>LENGTH</td>
<td>73 cm</td>
<td>81 cm</td>
<td>90 cm</td>
</tr>
<tr>
<td>WEIGHT</td>
<td>3.66 kg</td>
<td>5.29 kg</td>
<td>7.43 kg</td>
</tr>
<tr>
<td>RELATIVE CONDITION</td>
<td>1.064</td>
<td>1.11</td>
<td>1.13</td>
</tr>
<tr>
<td>DATE OF RECAPTURE</td>
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<td>MAY 8</td>
<td>MAY 7</td>
</tr>
<tr>
<td>REPLACED SONIC TAG PULSE RATE</td>
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<tr>
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<td>90 cm</td>
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<tr>
<td>WEIGHT</td>
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<td>6.86 kg</td>
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<td>WEIGHT LOSS</td>
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<td>0.57 kg</td>
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<td>RELATIVE CONDITION</td>
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<td>1.04</td>
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<td>JUNE 22</td>
<td>JUNE 16</td>
<td>JUNE 6</td>
</tr>
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<td>TOTAL NO. OF DAYS</td>
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<td>70</td>
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RESULTS.

A. SPAWNING MOVEMENT.

The three pike fitted with ultrasonic transmitters were caught by rod and line from the main body of the reservoir in depths greater than 10m. The fish were females, with mature ovaries. (Nikolsky 1963). Details of their lengths, weights and relative condition are given in Table 8.

The pike were released at a water temperature of 3.5°C. They were located in deep water (10m+) until 12 April when the water temperature increased to 7.5°C. (Appendix 1). During the next 24 hours the pike migrated, covering distances of 1000 - 2000m, towards the southern arms of the reservoir where the water was less than 10m deep.

Details of the spawning locations for the individual pike are given in Figures 9-11. The areas used by the pike for spawning were characterized by shallow water (0.5m - 3m) with a substrate of silt, tree debris and some filamentous algae, and were found where the reservoir had wooded margins.

Each of the pike were located on 2 - 3 spawning sites during the spawning season. They moved on and off these areas over a period of 2 - 3 weeks and covered distances of up to 750m between times on the spawning sites. Most activity on the spawning grounds was noted on bright sunny days.

The pike spawning season was from mid April to mid May, with the peak activity during the last week of April. After 15 May all fish caught had spawned.
Fig. 9. Spawning areas and locations of pike F73 from March 28th to May 4th.
Fig. 10. Spawning areas and locations of pike P81 from March 28th to May 8th.
Fig. 11. Spawning areas and locations of pike F90 from March 28th to May 7th.
B. RECAPTURE.

The transmitters were due to expire towards the end of the spawning period. The three fish were recaught by angling. Two of the fish were caught by a roach livebait and the third by a roach deadbait. The length of time angling for each pike ranged from 15 minutes to 10 hours. Although the bait was presented as near as possible to the sonic tagged fish, it was frequently taken by other pike that were in the vicinity.

After landing the fish and removing the hooks, the condition of the harness was assessed. There was little abrasion on fish F73 and F90, so the transmitter was removed and a new tag inserted into the harness. The harness of fish F81 was a looser fit and showed signs of abrasion at the points of entry of the surgical thread. This harness was removed and replaced by a modified version which positioned the transmitter alongside the dorsal fin and left the wounds free to heal.

The three pike were weighed and measured (Table 9) and appeared to be in good condition. F73 and F81 had completed spawning and their abdomens were flaccid, F90 had not fully spawned.

For the pike F73 and F90 the procedure of landing the fish, removing the hooks, replacing the transmitter, weighing, measuring and returning the fish to water took less than 10 minutes. F81 recovered from the second harness attachment and was released after half an hour in the keepnet.
C. POST SPAWNING MOVEMENTS.

After the transmitter change, tracking was continued. The pike F90 completed spawning on May 13-14th.

After spawning, movement was extensive. The pike covered distances up to 1.5 km. in a day, and were found in areas where prey fish were present in large shoals, often at inlets of streams and the weir pool. Pike caught by angling in these areas had a size range of 1 kg to 8.5 kg, and fish catches per rod hour were significantly higher. (Fig. 16).

Towards the end of May the sonic tagged pike moved over more restricted areas which may be termed home ranges (Hayne 1949), (Figs. 12-16). The pike were mostly found within 100m of the shore and in depths of less than 10m. The maximum linear distances and the areas of the home ranges calculated using the method of Rongstad and Tester (1969) are given in Table 10.

<table>
<thead>
<tr>
<th>TABLE 10. SIZE OF HOME RANGES OF ULTRASONIC TAGGED PIKE.</th>
</tr>
</thead>
<tbody>
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<td>Max. linear distance (m)</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>800</td>
</tr>
<tr>
<td>Area (ha.)</td>
</tr>
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</table>

Each home range had locations where the pike were most frequently found. These appeared to be related to areas where woodland and roads were in the valley before it was flooded. (Figs. 12-15).

Generally movement between these locations was direct or following a linear pattern with 180° turns occurring at 25 - 100m.
intervals. Random movement around their preferred locations also occurred. The boundaries of the home range were not rigid and the pike travelled distances up to 500m outside their usual area. However, this occurred rarely, a maximum of three times for each pike over a period of approximately one month's tracking.

As June progressed, the pike were more frequently found in shallow water of 0.5 - 3m amongst weed beds. Tracking became more difficult because of attenuation of the signal by the vegetation, and range could be as low as 10m.

Although there was only a small overlap of home ranges of the three sonic tagged pike, evidence from angling and visual observations indicated that varying sizes of pike were present within their home ranges. Therefore there is evidence that mature pike share the same habitat preference revealed by the sonic tagged fish, and numbered tag recaptures suggest that they may also remain in restricted areas or home ranges.
Fig. 12. Locations of pike F73 from May 4th to June 22nd in relation to features before flooding.
Fig. 13. Locations of pike F81 from May 8th to June 16th in relation to features before flooding.
Fig. 14. Locations of pike F90 from May 7th to June 6th in relation to features before flooding.
Fig. 15. Home ranges of the three ultrasonic tagged pike.
D. CIRCADIAN RHYTHMS AND FEEDING ACTIVITY.

Eight 24 hour tracking sessions and information gained from shorter term tracking sessions revealed that movement of the pike showed circadian rhythms. (Fig. 16).

The pike moved very little during the night. Most activity occurred during the day with peaks at dawn, mid morning and dusk. Light appears to influence activity as more movement over longer periods of time occurred on clear, sunny days. There were indications of seasonal variance, as peaks of activity, especially at dawn occurred earlier in June than the peaks in March.

The times when the pike were moving coincided with times when most fish were caught by angling. Therefore movement may be associated with feeding activity or foraging. (Plate 7). This was confirmed by the recapture of the sonic tagged fish, F73, F81 and F90 at 12.00 a.m., 12.30 p.m. and 9.30 a.m. respectively. All fish were caught when they were moving.

Extensive movements in May after spawning coincided with wider bands of fish captures. The most successful baits were 10-12 cm roach, but pike were also caught on bream, perch, carp, trout and mackerel deadbaits.

Examinations of stomach contents and regurgitation from angler caught pike showed that roach and perch were the most common species eaten. In June the pike were mainly feeding on 3-5 cm roach, bream and perch which were present in large shoals. Cannibalism, which is known to occur in pike populations was demonstrated when a large pike attacked a small pike (1.5kg) which was being reeled in by an angler. (Plate 8).
Movement recorded at 1/2 hourly intervals during 8 24 hr. tracking sessions.

Fig. 16. Movement and feeding activity

a) Peaks of movement as determined by ultrasonic tracking.

b) Monthly fish catches by angling.

- 1-2 Fish.
- 3-4 Fish.
- 5-6 Fish.
PLATE 7. Young pike feeding in aquarium. Pike generally catch prey by grasping it from the side and then turning it so the head end is taken first.

PLATE 8. Cannibalism occurs in pike populations. A pike caught by an angler is attacked by a larger pike.
E. END OF TRACKING.

Pike F81 was recaptured on June 16th at 10.20 a.m. by angling and the sonic tag and harness removed. Abrasion caused by the first harness had healed completely. The total tracking time was 80 days.

The transmitter of F90 ran down before anticipated. This fish was not located after June 6th, a total tracking time of 70 days.

Attempts to recapture F73 failed. The pike was located for most of the angling time in dense beds of algae, and therefore may not have been able to detect the bait. The transmitter ran down on June 22nd which made a total of 86 days tracking.

The last two tags were not recovered. The pike anglers were notified about their loss, but these fish were not caught.

The life of the tags was estimated to be about 45 days. Shelf life of transmitters is advertised as 1 year, but the average life of the second series of transmitters was less than the first. This indicates that estimations of lives of tags must take into account the age of the batteries prior to use. For the best performance it is recommended to replace expired batteries in transmitters just before reusing, so shelf time is minimized.

For fresh transmitters the manufacturers advertised life of 60 days may be expected, but this decreases if transmitters are not used immediately.
DISCUSSION.

The use of ultrasonic transmitters proved to be most successful for studying the movements of pike during spawning and their post spawning dispersion.

The pike left the deep water in the main body of the reservoir on 12-13 April and migrated 1-2 km to the spawning grounds. This was later than expected as Frost and Kipling (1967) record pike on the spawning grounds in Lake Windermere in mid March. The unusually cold winter and freezing over of the reservoir may have made water temperature lower than average at this time of year. The rise in temperatures from 5.5°C to 7.8°C during the second week of April may have been the environmental stimulus for the migration leading to the pike spawning season.

The spawning season lasted about a month (mid April - mid May). The sonic tagged pike were located several times on the spawning grounds over a period of 12 - 19 days and apparently spawned on 2 - 3 different areas. Minor and Crossman (1978) found that males of *Esox masquinongy* spawned at one site only, but females with different males spawned in one or more areas. R.H.K. Mann, (personal communication) said this is also true of the pike and the sonic tagged fish confirmed this female behaviour during spawning.

Movements of up to 500m linear distance occurred during intervals between the pike being on the spawning areas. There was evidence that pike were feeding during the spawning period. The sonic tagged fish were frequently found near shoals of prey fish during the intervals off the spawning grounds and ovulating fish have been
caught by anglers.

The spawning areas in Staunton Harold Reservoir were not typical of traditional pike spawning grounds where pike are described as spawning over submerged vegetation or inundated meadows (Svårdson 1948, Fabricius 1950, Frost and Kipling 1967). Fabricius and Gustafson (1958) found that the optimal spawning substrata for pike was a dense mat of short vegetation. McCarraher and Thomas (1972) discuss the ecological significance of vegetation to pike spawning. The spawning areas in the reservoir showed little evidence of aquatic vegetation, as temperatures were low and the reservoir also has a barren draw down zone at the margins. The spawning substrata was silt, tree debris and some algae. Several investigators have commented that pike year class strength is closely related to type and abundance of aquatic vegetation (Clark and Steinbach 1959, Forney 1967). Little information was gained on the 0 - 60 cm pike (Chapter 1); but there are indications that small pike are not present in large numbers.

During the first few years after flooding, reservoirs provide excellent spawning substrata for coarse fish, and are very productive. If survival of pike fry is now comparatively low in Staunton Harold reservoir because of a lack of vegetation for spawning, it may be advantageous to provide artificial substrata. Alternatively, the water levels could be kept above the limits of the usual draw down zone during the spawning season so vegetated banks may be temporarily flooded. This may improve the reservoir as a coarse fishery.

Movements were extensive as the pike were dispersing after spawning. The feeding rate of pike was highest during May, as
shown by numbers of fish caught by angling during this month. Popova (1978) also found the daily ration of pike to be highest during May.

Movement was greatest during the two weeks after spawning which is further evidence that movement is associated with feeding activity. The low relative condition of the pike after spawning and rising temperatures may be responsible for the increased feeding rate of pike in May.

The three sonic tagged pike did not return to their pre-spawning locations. Therefore, homing, in the sense of returning to a winter home range, did not take place. However, the three pike occupied restricted areas from mid-May in different parts of the reservoir, and these areas may be termed the summer home ranges of these pike.

A home range is defined as the area over which an animal normally travels (Hayne 1949). A territory is any defended area (Nice 1941), usually for a more restricted area within the home range. The use of the term 'territory' implies an aggressive response for the protection of an area against invasion; home range does not necessarily imply aggressive action. There is no record of aggressive behaviour between adult pike such as occurs between brown trout - *Salmo trutta* - (Jenkins 1969), therefore, the restricted area occupied by the pike is considered to be a home range rather than a territory.

The summer home ranges of the three sonic tagged pike had a linear distance of 800 - 1250 m, and were generally in water depths of less than 10 m. However, there is some doubt as to whether the whole pike population establishes home ranges.
Diana et al. (1977), using stomach implanted ultrasonic transmitters studied the movements of nine pike of weights 1.6 to 4.1 kg. for 5 - 47 days in Lac St. Anne, Alberta. They found that none of the pike established well defined home ranges, were usually within 300 m of the shore and in water less than 4 m deep. Daily pike movements were from 0-4000 m, but mostly less than 1000 m. When the fish moved within confined areas these had a radius of approximately 500 m and were occupied for up to 9 days.

Malinin (1969, 1970b) using externally attached ultrasonic transmitters on pike in the Rybinsk Reservoir, Russia, thought that pike were sedentary occupying home ranges of 50 -150 m in diameter where the bottom is flat, but moving up to 500 m along an old river bed. However, the transmitters he used only lasted for 50-60 hours (Malinin 1970a, 1971) and this is insufficient time to determine if a home range has been established.

Minor and Crossman (1978) using radiotelemetry studied the movements of sixteen adult muskellunge (*Esox masquinongy*) for 18 months. They found that muskellunge established well defined home ranges in summer and winter months which were proportional to the size of the fish. They left these home ranges in spring and autumn when the water temperatures were 8 -15°C. This species is closely related to the pike, and behaviour and choice of habitat appears to be similar.

Other workers using tag-recapture methods suggest that pike occupy restricted areas. (Halme 1958, Johnson 1966, Makowecski 1973).

The conclusion reached is that the size and shape of the home ranges of pike are variable, possibly depending on population density,
abundance of prey, vegetation, depth and topography of the lake. Diana et al. (1977) discuss their results by suggesting that a pike population consists of both transients which move extensively, and residents which remain in a restricted area, (Funk 1957, Jenkins 1969), with the net effect that only part of the population may establish a home range. Wynne Edwards (1962) suggests that transients are the non breeding part of the population. Evidence from the Staunton Harold pike suggests that existence of a home range may be correlated with abundance of prey. Movement appeared to be a foraging activity, and each home range extended to areas where there were abundant shoals of prey fish. If food is scarce, it seems likely that greater distances would be covered in search of prey, and boundaries of the home range would be extended or pike may become transients and no longer remain in a restricted area.

There were different types of movement on the home range. Fish do not remain within a home range by chance and positive orientation takes place. (Gerking 1953, Gerking 1959, Jenkins 1969). Tytler et al. (1977) recorded linear movement patterns with 180° turns for Salmo trutta on a home range, and it was noticed that the pike occasionally showed this type of movement on their home ranges.

Movement of the sonic tagged pike showed circadian rhythms. There was little movement during the night, and the main peaks of activity during the day were at dawn, midmorning and dusk. Malinin (1970) recorded peaks at dawn and dusk and a small peak at midday. As movement corresponded with the times of anglers catches, it may be associated with feeding activity. However, behaviour of fish are also influenced by the behaviour of prey, light and oxygen
concentration (Alabaster and Robertson 1961) so these factors may also influence the peaks of activity. However, for pike anglers the most productive times for fishing are dawn, midmorning and dusk.

Distribution of pike in Staunton Harold reservoir is seasonal. Evidence from the sonic tagged fish and angling suggests that winter and early summer locations are closely associated with features in the reservoir before it was flooded, particularly woodland and old hedgerows. As June progressed, the pike were more frequently located in vegetated areas in shallow water of less than 4 m. This habitat preference of pike in the summer was also noted by Kipling and Frost (1970), Malinin (1971b) and Diana et al. (1977).

The Smith-Root tracking equipment proved to be a successful means of studying the pike in its natural habitat. There was some doubt that the operation and the attachment of the transmitter externally would affect the behaviour of the pike. Recapture of the three sonic tagged pike showed that they had spawned and were in relatively good condition, which indicated that the transmitters were not impairing the pike in any way.

Malinin (1970b) also said that externally attached transmitters did not have a deleterious effect on *Esox lucius*. The harness allowed the transmitters of F73 and F90 to be rapidly replaced so the fish were returned to the water with minimal disturbance. The harness of F81 was replaced because of abrasion caused by a loose fit of the harness. To avoid abrasion the harness must be attached securely. The modified harness with the tag positioned alongside the dorsal fin was tested, and after the second recapture of F81 indicated that this may be a better position for the transmitter,
particularly in weedy habitats.

The study is limited by the life of the transmitters. The Smith-Root transmitters (SR69B) had been modified on request to increase their life to 60 days. Fishing to recapture the fish took place after 40 days of tracking to allow a safe margin before the batteries expired. This was successful for the first series of transmitters. Their average actual lives were almost 60 days. The second series had shorter lives (30 - 45 days). Summerfelt and Hart (1971) found that temperatures did not significantly affect transmitter lives, so the shorter life was attributed to the storage of the transmitters, and deterioration of the batteries. In a limited budget project, it is a great advantage to be able to regain the transmitters after use. For the best performance, replacement of batteries should take place just before refitting to a fish, as even with careful storage, the batteries did depreciate resulting in shorter lives when the transmitters were activated.

The main problem of ultrasonic biotelemetry was attenuation of the signal. Vegetation, algal blooms and turbulence could reduce the range to as little as 10 m from over 750 m in ideal conditions. Crossman (1977) had this difficulty in lakes where he was tracking and subsequently changed to radiotelemetry. However, in Staunton Harold Reservoir attenuation only became a problem in June when the pike were in known areas, so locating them, even with the minimum range, was not too difficult. In weedy habitats or meandering rivers the use of ultrasonics is limited, and a radiotelemetry system would be recommended.
The use of biotelemetry has potential as a fisheries management tool. The present study indicated that locations of individual fish can lead to the establishment of the preferred habitats of species, spawning grounds and of seasonal movements and migrations. This could be of value in circumstances of deteriorating fish populations and where recreation is allowed on water bodies. Information on behaviour, daily movements and circadian rhythms of fish would be useful in planning methods of fish capture, and would also be of special interest to anglers.

The use of biotelemetry in this study gave evidence that the ecology of pike in an artificial reservoir, where aquatic vegetation was not well established, was influenced by features present before drowning of the valley. Distribution and habitat preference of the pike was related to remains of woodland, hedgerows, buildings and the original stream bed, but as summer progressed they were more frequently found in water depths of less than 4 m. In the absence of vegetation in April, spawning took place on tree debris and silt, which were located mainly where the reservoir had wooded banks. It may be concluded that Staunton Harold Reservoir is a good pike fishery, as although the pike's traditional habitat amongst vegetation is sparse, the reservoir provides alternative pike habitats and substrata for spawning. The pike has been proved to be an asset to any normal fishery by its selective control of abundant, stunted and diseased fish, the ability to control its own population by cannibalism, and its high growth rate and size attained which makes it of particular interest as a sport fish.
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the stomachs of fish.  

numbers, year class strengths, production and food consumption  
of pike, Esox lucius L., in Windermere from 1944 to 1962.  

of pike (Esox lucius) from Windermere.  


   Hamlyn, London.

   M.S. Thesis. Univ. of Alberta. 239 pp.


APPENDIX 1.

Weekly temperatures and pH of the raw water (middle draw off) for the year 1979, and spawning times of pike, (*Esox lucius* L.), perch (*Perca fluviatilis* L.) and bream (*Abramis brama* L.).

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APPENDIX 2. Macrophytes present in Staunton Harold Reservoir, October 1979, listed according to Dandy (1958).

Ranunculus sp. (Ranunculaceae).

Ceratophyllum demersum L. (Ceratophyllaceae).

Rorippa nasturtium-aquaticum (L) Hayek (Cruciferae).

Rorippa amphibia (L) Bess. (Cruciferae).

Callitriche sp. (Callitrichaceae).

Polygonum amphibium L. (Polygonaceae).

Myosotis sp. (Boraginaceae).

Solomon duclamara L. (Solanaceae).

Veronica beccabunga L. (Scrophulariaceae).

Mentha aquatica L. (Labiatae).

Callitriche sp. (Callitrichaceae).

Potamogeton pusillus L. (Potamogetonaceae).

Potamogeton crispus L. (Potamogetonaceae).

Juncus inflexus L. (Juncaceae).

Juncus effusus L. (Juncaceae).

Lemma minor L. (Lemnaceae).

Glyceria maxima (Hartm.) Holmberg, (Gramineae).

Phalaris arundinacea L. (Gramineae).
APPENDIX 3.

a) Computer programme for finding the length-weight regression coefficients log a and b from the formula Log W = log a + b log L. (p. 16). The calculated lengths and weights for actual values are found. Relative condition is computed for $K_n = \hat{W}/W_0$ (p. 18).

Averages of length, weight and relative condition are given.

GO

SUBROUTINE MAIN

C

IMPLICIT REAL*8(A-H,O-Z)
REAL*8 W(99), CF(99), L(99), N(99)
N=96

C

96 IS THE NUMBER OF THE DATA POINTS, WHICH HAVE BEEN USED.

READ (5,+) (L(I), I=1,N), (W(I), I=1,N):

AVER=0.0
AVERL=0.0
AVERN=0.0
DUM=0.0
QUM=0.0
TUM=0.0
NT=N
RUN=0.0

DO 11 I=1,NT

DUM=DUM+DLOG10(W(I))
QUM=QUM+DLOG10(L(I))+(DLOG10(W(I)))
TUM=TUM+(DLOG10(L(I)))+2

RUN=RUN+DLOG10(L(I))

11 CONTINUE

AN=(QUM+TUM-RUN+QUM)/(NT-TUM-RUN+RUN)

CL=(DUM-NT+AN)/RUN

WRITE (1,16) AN,CL

16 FORMAT(5X,'LOGC=',I13,6.E10X,'SHALF=',I13,6)

DO 1 I=1,NT

AVERL=AVERL+L(I)

AVERN=AVERN+W(I)

Y(I)=(AN+CL+DLOG10(L(I))

Y(I)=10**+Y(I))

CF(I)=(W(I)/Y(I))

AVEX=AVEX+CF(I)

C(I)=10**+(DLOG10(W(I))-AN)/CL

15 FORMAT(1X,'CALCUL.',3(F7.3,2X),'-------','ACTUAL',

# 2(F7.3,2X),'+++++I=',I3)

CONTINUE

AVERL=AVERL/N

SDL=0.0

XDN=0.0

AVERN=AVERN/1.0
DO 2 I=1,N
XDW=XDW+(W(I)+W(I))
SDL=SDL+(L(I)-AVERL)*2
2 CONTINUE
WRITE(1,100) XDW, SDL
100 FORMAT (20X,'SUM OF W+2 ',D13.6)
NM=N-1
SDL=SDL/NM
SDW=(XDW-(AVERN*AVERN/96.))/(96.*95.)
SDL=DSORT(SDL)
SDW=DSORT(SDW)
WRITE (1,30) SDL, SDW, AVERL, AVERN
30 FORMAT (2X,'ST. DEV. OF L.',D13.6,2X,'ST. DEV. OF W.',D13.6)
# /
# 2X,'AVER. L.',D13.6,2X,'AVER. W.',D13.6)
AVER=AVER/N
WRITE (1,31) AVER
31 FORMAT (2X,'AVERAGE OF THE W/Y FACTOR IS ',D13.6)
STOP
END

GO

LOGC=-0.522782D 01          SMALN= 0.309351D 01
CAL. 48.97  0.82  1.21  --ACT  46.00  1.00
CAL. 44.81  0.88  0.96  --ACT  47.00  0.76
CAL. 53.30  1.35  0.96  --ACT  54.00  1.30
CAL. 68.26  1.43  1.33  --ACT  55.00  1.90
CAL. 55.83  1.51  0.99  --ACT  56.00  1.50
CAL. 57.00  1.60  1.00  --ACT  57.00  1.60
CAL. 54.60  1.78  0.79  --ACT  59.00  1.40
CAL. 68.26  1.78  1.07  --ACT  59.00  1.90
CAL. 57.00  1.78  0.90  --ACT  59.00  1.60
CAL. 55.83  1.83  0.82  --ACT  59.50  1.50
CAL. 58.13  1.92  0.88  --ACT  60.50  1.70
CAL. 57.00  2.07  0.77  --ACT  62.00  1.60
CAL. 59.22  2.18  0.23  --ACT  63.00  1.80
CAL. 65.85  2.29  1.09  --ACT  64.00  2.50
CAL. 72.73  2.40  1.42  --ACT  65.00  3.40
CAL. 65.85  2.40  1.04  --ACT  65.00  2.50
CAL. 61.27  2.40  0.83  --ACT  65.00  2.00
CAL. 65.85  2.52  0.99  --ACT  66.00  2.50
CAL. 67.51  2.52  1.07  --ACT  66.00  2.70
CAL. 60.26  2.52  0.75  --ACT  66.00  1.90
CAL. 63.19  2.58  0.85  --ACT  66.50  2.20
CAL. 73.42  2.58  1.36  --ACT  66.50  3.50
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AVER. L = 0.7754170 02
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*** STOP ***
ST. DEV. OF W = 0.2127240 00
AVER. W = 0.4335600 03
OK,
b) Computer programme used for drawing a straight line between points using the method of the least squares and Ford Walford plots are drawn for i) Males and females, ii) Females, iii) Males.

```
* * *

MASTER MISTRESS
RFAL X(11), Y(11)

PROGRAM TO PLOT A STRAIGHT LINE

CALL C1091N
DO 21 IR05=1,3
READ(5,100)N,X(I),Y(I),I=1,N
100 FORMAT(I2,10(2F0.0))

CALL PFNSEL(1,0.0,0)
CALL AX1PLO(10,-1,0,0,1,20,20,0,0,120,0,0,120,1,1,1,1,1,1)
CALL PFNSEL(2,0.0,0)
CALL GRAYM(X1,Y,N,1.0)
CALL GRAMOV(0.0,0.0)
CALL PFNSEL(3,0.0,0)
CALL GRA1N(120,120)
CALL PFNSEL(4,0.0,0)
SXY=0.0
Sx=0.0
Sy=0.0
Spx=0.0
Spv=0.0
DO 10 I=1,N
Sx=Sx+X(I)
Sy=Sy+Y(I)
Spx=Spx+Sx+X(I)*X(I)
Spv=Spv+Spv+Sv+Y(I)*Y(I)
10 SXY=SXY+X(I)*Y(I)

GRAD=(N*SXY-Sx*Sy)/(N*Spx-Sx*Sx)
XR=Sx/N
YR=Sy/N
C=VB-GRAD*XR
WRITE(6,101)N,(X(I),Y(I),I=1,N)
101 FORMAT(120I5,2F8.4)
WRITE(6,104)GRAD,C
104 FORMAT(11EQUATION OF LINE IS Y=1,1V=1,F6.4;1X1;F7.4)
Y2=GRAD+120.0*C
CALL GRAMOV(0.70)
CALL GRA1N(120., Y2)
CONTINUE
CALL DEFEND
STOP
END
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APPENDIX 4.

Battery replacement of the Smith-Root (SR69B) disposable ultrasonic transmitter.

The tag is composed of 2 parts. (Fig. a). The transmitter and pulse oscillator are separated from the battery housing by a 2 mm plastic seal. 3 wires protrude through the seal; battery positive and negative (via the switch wire) and a positive supply of approximately 2.6 volts for the transmitter oscillator. The whole battery stack is hermetically sealed with epoxy resin to make it water tight.

The tag was opened to replace the battery stack. (Fig. b). A cut was made around the circumference of the tag, adjacent to the battery side of the 2 mm seal, and 2 cuts were made either side down the battery case. The case was then split open exposing the batteries embedded in epoxy resin which was chipped away from the battery pack with care not to sever the transmitter connecting wires. When this was done the transmitter wires were disconnected from the battery stack, and the complete stack removed from the tag. The connecting wires were taped together onto the end of the seal to prevent fracture.

The tag was then placed in a centre lathe and the case was made parallel and true for 5 mm along the case. A new case was constructed from polypropylene to the following dimensions for a 4 battery stack. (Fig. c).

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Length</td>
<td>2.8 cm.</td>
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<tr>
<td>ID</td>
<td>1.461 cm.</td>
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<tr>
<td>OD</td>
<td>1.740 cm.</td>
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</tbody>
</table>


The batteries (MA135 mercury cells) are in series and were connected by soldering short lengths of hook up wire (0.025 mm²) to each battery. (Fig. a) and glass epoxy insulating tape was placed between each cell. The battery stack was reconnected to the transmitter. The short red lead was connected to the bottom centre of the first battery and the longer red lead to the outside case of the second battery in the stack. The long black wire was taped to the outside of the stack and this formed one of the switch wires. A short length of hook up wire was soldered to the top of the stack to form the other switch wire. The insulation sleeving was left on the switch wires and they were twisted together. The case was then partially slid over the stack with the switch wires protruding through the end of the case. The tag was inverted and a small amount of Araldite rapid epoxy was smeared round the transmitter case. The battery case was filled with 3M soft epoxy potting compound and the two halves of the case fitted together and left to set. Setting times of both compounds was 10 minutes but 8 hours were given to ensure full hardening.

Finally the 2 switch wires were stripped and taped to the outside of the case to prevent accidental activation of the tag.

The use of soft potting compounds allows the case to be opened more easily for future battery changes.
Fig. a) Construction of tag.
b) Removal of case.
c) Fitting of new battery case.