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Density, size distribution and home range of American eels, *Anguilla rostrata*, in a Massachusetts salt marsh

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Synopsis

Local American eel stocks were studied by mark-recapture methods along 600 m of tidal creeks in Great Sippewisset Marsh, Falmouth, Massachusetts, during summer 1979. The estimated stock density was 350 eels, equivalent to 875 fish ha^{-1}, and movement of individual American eels over the five week study was usually less than 100 m. Large American eels were found to predominate in the wide marsh creeks whereas smaller American eels predominated in narrower creeks at the landward side of the marsh. Territoriality is suggested as a mechanism for maintaining differences in distribution of size classes and a limited home range.

Introduction

Few studies have been undertaken to determine the ecology of American eel in inland and coastal waters, despite a growing international market for anguillid eels (Lane 1978). The age and growth rate of the American eel in fresh waters has been studied by Smith & Saunders (1955), Ogden (1970), Gray & Andrews (1971) and Helfman et al. (1984a, b).

Electrofishing and poison techniques have been used to estimate the relative abundance of American eel. These estimates have varied from 20% of total fish stocks in a New Jersey stream (Ogden 1970) to between 0 and 77.2% of total fish stocks in New Brunswick maritime lakes (Smith & Saunders 1955). These techniques are unlikely to measure the total density nor are they useful for measuring other parameters such as home range. Density estimates for American eels have been obtained by capture-mark-recapture techniques and include >300 fish ha^{-1} in a brackish water area in Rhode Island (Bianchini et al. 1982) and 232–636 fish ha^{-1} in an inshore area of a Vermont Lake (LaBar & Facey 1983).

LaBar & Facey (1983) also noted little evidence for homing using 16 radio-tagged American eels. This is in contrast to the findings of other authors. Gunning & Shoop (1962) found a small, short term home range of 200 linear feet for American eels in two headwater streams in Louisiana. Hurley (1972) found a 'suggestion of territoriality' amongst American eels in Eastern Lake Ontario and Vladykov (1971) found evidence for homing of transplanted American eels in New Brunswick. More recently, Bianchini et al. (1982) concluded that American eels establish home territories for a short period of time, in between erratic movements from area to area. Helfman et al. (1983) studied the movement and distribution of eight immature American eels in a Georgia estuarine stream, using ultrasonic telemetry. They concluded that limited

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movements and regions of concentrated activity may be evidence of home ranges within creeks.

We report investigations of density, size distribution and home range of American eels in a Cape Cod salt marsh.

Methods

American eels were trapped along 600 m of a tidal creek system in Great Sippewisset Marsh, Falmouth, Massachusetts, from June 28–August 5, 1979. Commercially available minnow traps (Gee Co.), baited with mussels, were used to catch American eels ranging from 15 to 63 cm in length. The mesh size of 5 mm allowed American eels smaller than 15 cm to escape. The maximum size of American eel was restricted by the small size of these traps; however, no larger American eels were caught in a much larger trap sited close to our study area (unpublished data).

The survey area was sampled in two stages: sites 1–9 were trapped from June 28–July 10, and sites 10–23 were trapped from July 11–August 5 (Fig. 1). Sites 1–9 covered an approximate creek area of 0.14 ha and sites 10–23 an approximate creek area of 0.26 ha. To study size distribution we divided the creek system into four sections, each differing in width, sediment type, depth and duration of tide cover (Table 1). Intermediate sites 9, 14–16, 22 and 23 were omitted from this analysis to further delineate the sections.

Twenty three traps were spaced regularly (approximately every 25 m, one trap per site) throughout the creek system, at sites insuring water cover at low tide and offering cover for American eels, such as obstructions in the creek and overhanging banks. Traps were attended daily and captured American eels were marked with a series of notches in the continuous dorsal/anal/caudal fin using a site specific code. Total lengths were measured and distinguishing marks noted so that individual American eels could be recognized in the case of multiple recaptures. After marking, American eels were released at the site of capture.

The density was estimated using the Jolly method (Jolly 1965) designed to consider multiple recaptures and mortality. The assumption we made for the Jolly method was that the stock of American eel is a 'single' stock, present in an area within whose boundaries the animals are free to move and mix (Jolly 1965). There should be no restriction to the free movement of American eels in the salt marsh system as the creeks are interconnected and at high tide American eels may easily travel directly across the marsh. Sites 1–9 were analysed separately from sites 10–23, as they were trapped at different times. Size distributions were obtained for each section (A–D, Table 1) and for the overall total. These distributions were then compared using the G-statistic (Zar 1984). At the back of the marsh the creeks tend to be shallow and narrow, whereas at the seaward side they are broader and deeper, therefore, analysis of variance (Zar 1984) was used to establish if size distribution of American eels varied significantly with distance from the creek mouth (an indication of habitat preference). Home range defined as 'area over which an animal normally travels' (Gerking 1953), was estimated by comparing the total distance travelled by each recaptured eel. This was then converted to an areal estimate by multiplying distance travelled by the

Table 1. Description of creek sections studied in Great Sippewisset marsh from June 28–July 10, 1979 (sections A and B) and from July 11–August 5, 1979 (sections C and D). Depth was measured simultaneously for all sections at high tide, using poles painted with water soluble paint (site numbers refer to Fig. 1).

Section	Sites	Length (m)	× Depth (m)	× Width (m)	Area (m^2)	Bottom type
A	1–5	80	1.37	4	320	Sandy/mud edges
B	6–8	85	1.63	7	595	Sandy
C	10–13	100	1.13	16	1600	Soft mud/sand
D	17–21	160	0.83	1	160	Soft mud

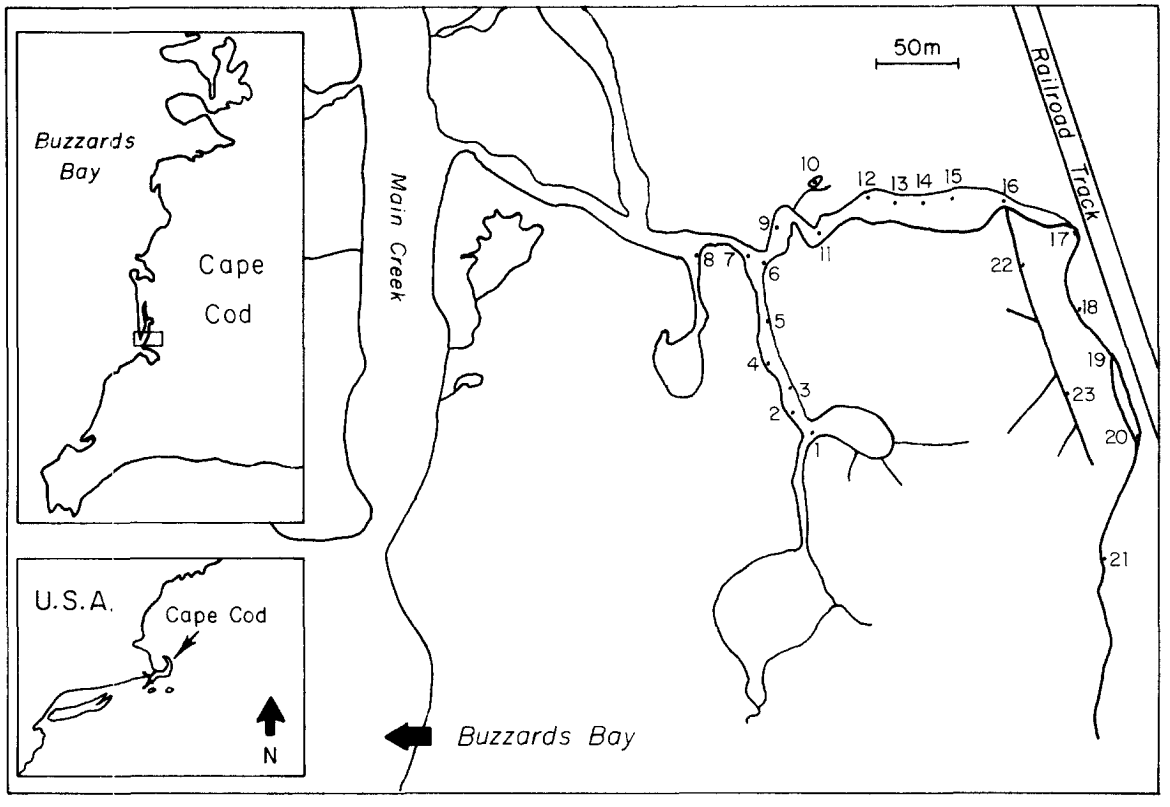

Fig. 1. A map of the area studied in Great Sippewisset Marsh. The map shows individual sites (1–23) trapped during summer 1979.

corresponding creek width at mean high tide. The G-statistic was used to establish whether the size distribution of recaptured eels was statistically different from the size distribution of the total number of eels caught. The G-statistic was also used to establish whether there were differences in the distance travelled by large (>35 cm) versus small (<35 cm) American eels. It should be noted that this size distinction may not only reflect age, but also sex as male American eels seldom grow larger than 40 cm length (Helfman et al. 1984a). At present no data are available on the relative abundance of males and females in this salt marsh. As these size groups were arbitrarily chosen, linear regression analysis was also used to test whether there was a relationship between distance travelled and size of American eel. To test for bias due to differences in recapture interval, linear regression analysis was also used to test for a correlation between recapture interval and distance moved.

Results

Eel stock

During the study, 243 individual American eels were marked and 67 were recaptured (some individuals several times). The mean density estimate for sites 1–9 was 130 eels ± 43 (standard deviation), equivalent to 928 fish ha^{-1}, and for sites 10–23 as 220 ± 88, equivalent to 846 fish ha^{-1}. On the assumption that the home range is small, addition of the two estimates gives a rough estimate of 350 American eels (>15 cm) for the total area of creek studied, equivalent to 875 American eels ha^{-1}.

Size distribution

Captured American eels averaged 30.6 cm, ranging 15–65 cm with a peak in the 20–30 cm size class (Fig. 2). The size distribution of recaptured American

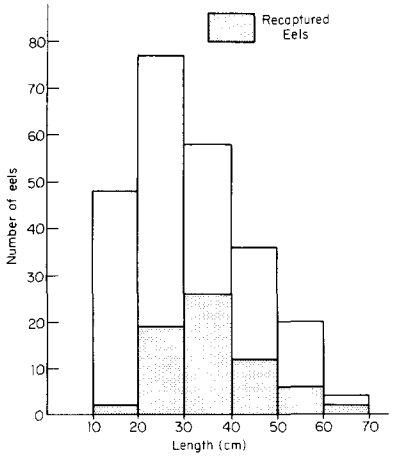

Fig. 2. Size distribution of the total number of American eels marked in Great Sippewisset Marsh from June 28–August 5, 1979. The stippled area of each graph represents the number of eels recaptured in each size group. Multiple recaptures are only represented once.

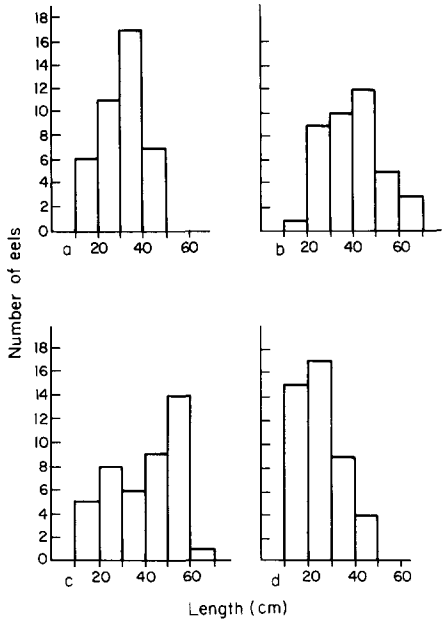

Fig. 3. Size distributions of American eels caught at each section (Table 1) during the study in Great Sippewisset marsh from June 28–July 10, 1979 (sections a and b) and from July 11–August 5, 1979 (sections c and d).

eels was significantly different from the size distribution of the total catch (G-test, $G = 14.51$, $DF = 5$, $P<0.05$). Size distributions of American eels remained stable for sections A and B throughout period one and sections C and D throughout period two (no significant variation in mean length of American eel per section per day). Therefore, we considered it justified to compare total size distributions for the four sections (Fig. 3a–3d). G-tests were run between pairs of sites and the estimates of similarity of distribution obtained (Table 2). The results indicated significant differences in length distribution between the four sections. The size distribution of American eels was found to vary significantly with distance from the creek mouth (Table 3) (analysis of variance, $F = 18.68$, $DF = 4,236$, $P<0.001$). Smaller American eels predominated in the narrow, soft bottomed creeks of the landward marsh, whereas large American eels predominated in the broader soft mud to sandy bottomed creeks of the seaward marsh.

Table 2. Comparison of size distribution of American eels captured in Great Sippewisset marsh from June 28–August 5, 1979. Sections are compared against each other by constructing a contingency table for each pair and calculating the G – statistic, degrees of freedom are calculated as (columns-1) (rows-1) (Zar 1984).

Sections	G-Value	d.f.	P
A vs B	14.89	5	<0.05
A vs C	21.04	5	<0.05
A vs D	8.25	3	<0.05
B vs C	9.32	5	>0.05
B vs D	26.56	5	<0.05
C vs D	25.73	5	<0.05

Table 3. Variation of size distribution of American eels caught in Great Sippewisset marsh between June 28 and August 5, 1979, with distance from the most seaward site. The distance from the most seaward site is related to creek size, with creeks becoming narrower towards the back of the marsh.

Range (distance from seaward site)	N	Mean American eel size (cm)	Std. Dev.
0–100 m	39	39.04	12.12
101–200 m	96	35.18	11.81
201–300 m	25	24.91	8.79
301–400 m	61	25.94	9.83
401–500 m	20	23.20	6.58

Home range

No significant differences in distance moved (Fig. 4) were found between large (>35 cm) and small (<35 cm) American eels (G-test, G = 6.96, DF = 12, P>0.05). Linear regression analysis indicated no relationship between distance moved and size of American eel (r = 0.114,, DF = 65, P>0.20), nor between distance moved and recapture interval (r = 0.065, P>0.20). Areal analysis of home range gave a mean estimate of 209 m^2 (range, 0.0–2,200 m^2; SD, 394). Ninety three percent of American eels travelled less than 100 meters, the modal distance travelled being less than 20 meters. Two American eels (>35 cm) travelled over 200 meters (Fig. 4). Thirty six recaptures occurred in, or close to (<20 m), the same trap as their first capture indicating comparatively little movement of individuals throughout the study period. Twenty American eels were recaptured more than once, of these, five were recaptured more than twice, all greater in size than 38 cm. Two eels greater than 50 cm length were captured five times, one at the same site each time and the other, three times at the same site and twice within 20 m of that site. We suggest that this may be indicative of a limited, or perhaps established, home range for the large eels.

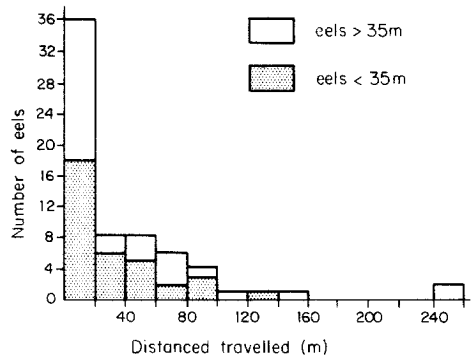

Fig. 4. The distance travelled by all the recaptured American eels in Great Sippewisset Marsh during the period June 28–August 5, 1979. The number of recaptured American eels is plotted against the distance between the site of initial capture and the site of recapture. The stippled area on the graphs represent the number of American eels <35 cm in length recaptured in each distance group.

Discussion

It is important to note that due to trap limitations data are limited to American eels ranging from 15–63 cm length. Three factors may influence the estimate: (1) The placement of traps at sites offering cover for American eels may result in an over estimation of density due to trapping near preferred American eel habitat (G. Helfman, personal communication). (2) There was a difference in size distribution between all recaptured American eels and total number of American eels caught. Larger American eels were recaptured more frequently than smaller American eels (<30 cm length), with only two American eels recaptured in the <20 cm size class. Either trapping of small American eels was inefficient and they were more numerous than total size distribution suggests, or retrapping of small American eels was inefficient, due to trap avoidance, mortality, or differential movement. As a result, stock size may be overestimated. (3) The estimate does not take into account mixing of eels between the study area and the neighbouring creeks. However, the limited home range of the American eels suggests that migration to and from the study sites was minimal during the study period, with only the peripheral sites (1 and 8) possibly affected.

There are few data available on densities of the American eel in salt marsh creeks. Bianchini et al. (1982) estimated a density greater than 300 American eels ha^{-1} in the Narrow river, Rhode Island, which is considerably lower than our estimate of 875 American eels ha^{-1}. LaBar & Facey (1983) quote unpublished data from P.T. Polloni and coworkers of American eel density in Massachusetts salt marshes as about 1 per 10 meters of shoreline. The American eel density we obtained is equivalent to about 1 per 1.7 linear meters of salt marsh creek and would suggest that Polloni's figure is an underestimate. Other estimates have been confined mainly to smaller American eel stocks in lakes (Smith & Saunders 1955, Rupp & DeRoche 1965, LaBar & Facey 1983). The closest to our estimate is LaBar & Facey's estimate from a bay in Lake Champlain, Vermont, of 232 to 636 eels ha^{-1}.

Gerking (1953) states that 'the fish population of

a small stream may be thought of as a series of discrete natural units rather than as a single homogenous freely mixing group'. This is the apparent situation found in the Sippewisset salt marsh among eels, indicated both by size distributions and limited movement of recaptured eels between sites. We speculate that large eels establish territories in the wider marsh creeks, restricting small eels to the narrower creeks at the back of the marsh. In support of this speculation, G. Helfman (personal communication) has found evidence of restricted movement by large American eels in a cave-spring in Florida, based on diving observations, and has also observed larger American eels dominating smaller American eels in both field and laboratory. Hurley (1972) has suggested territoriality in lake dwelling eels. To establish the existence of territoriality in the Sippewisset marsh, further behavioral and manipulative studies, with consideration towards such factors as differential prey availability and selection, and vulnerability to predation, are required.

The general findings of this study were supported by trapping carried out over a five day period during the summer of 1980. Large eels were trapped in large creeks and small eels were far more abundant in the narrow creeks at the back of the marsh. Out of a total of 95 American eels caught, three were definitely identified as marked from the previous year and a further 20 had scars that could have been healed marks. It is extremely difficult to distinguish naturally occurring scars from marks caused by tagging, however if the number of eels caught with apparently healed fin notches were all recaptures from the previous year, it would suggest fairly slow recruitment.

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