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Migratory behaviour of displaced homing yellow eels, *Anguilla anguilla*, in the North Sea

by

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Abstract

Yellow (stationary) eels (*Anguilla anguilla* L.), tagged by ultrasonic transmitter, were displaced from the Limfjord area to the German Bight, and to a releasing point in the central North Sea. The homing eels were tracked, taking a compass course in a South-easterly direction (140°). Combined with earlier tracking courses the compass swimming course was 126° and significant. The observed homing behaviour is consistent with earlier results of conventional tagging experiments. Swimming speed 1.5 km/h was below earlier measured average velocity values. Employing a pressure sensing transmitter attached to one specimen preliminary data on swimming depth could be obtained, indicating a preferred migratory depth between 4 and 18 m at a total water depth of 41 m. Avoidance behaviour of inshore shallow waters is discussed.

Introduction

In a number of tagging and transplantation experiments yellow (stationary) eel exhibited the ability of homing (see Lit. cit. by Tesch, 1973, pp 167 - 171) when displaced for more than 1oo km. Successful homing was performed in rivers and in open sea areas. The mechanism of orientation in homing eels as well as in other species is unknown. Although investigations on this topic using the conventional tagging method rarely ever yield further essental results, field studies are necessary to elucidate behaviour during the search of the home area.

Promising first experiments have started applying the technique of tracking eels tagged by ultrasonic transmitters (Tesch, 1974 a). Eels captured in the Elbe estuary, as well as specimen from the Baltic when released East of the Isle of Helgoland could be traced following a south-east direction towards the German mainland the reverse to that exhibited by migratory silver eels. This behaviour would have guided the Elbe estuary specimens very soon to their home area situated South-East of the releasing point. To examine if this described South-East trend also would occur in the eels originating from a home area located farther North, four Limfjord specimens were released for tracking in two different places of the North Sea.

In order to obtain data on swimming depth, a pressure sensing transmitter device (Stasko and Rommel, 1974) was attached to one of the specimens.

Material and Methods

All four specimens (Nos. V - VIII in continuation of the earlier experiment, Tesch, 1974 a) were female silver eels and derived from commercial catches of the Limfjord region (Danmark): located about 3oo km NE (1o - 4o^{o}) from the different releasing points. The eels were captured one to three weeks in advance of the tracking experiments. Eels Nos. V, VI and VIII measuring 8o cm in length and weighed 1ooo g each, while No. VII measured 86 cm weighing 15oo g. Eels Nos. V and VI were released about 2o km WSW of the Isle of Helgoland. Eels Nos. VII and VIII tracking courses were started SE off the White Bank, an area in the central North Sea (position about 54^{o} 42'N 6^{o} 36'E) thus not as much influenced by the tidal current as the Helgoland area (Fig. 1).

The ultrasonic transmitter tags (e. g. Tesch, 1972, 1974 a) were in three cases products of Smiths Root Electronics (USA) with a power of 46 or 52 dB rel 1μb, 1 m (eels Nos. V, VI, VIII). Eels No. VII was equipped with a pressure sensing transmitter (p-1oo) described by Stasko and Rommel (1974), developed by the Electrical Engineering Department, University of New Brunswick, Fredericton, Canada and produced by Epitek

Electronics, Canada. The transmitters were cylindrical 7o x 16 mm, weighing 3o g in air, using the frequency 7o - 74 kHz and the pulse repetition rate, depending on depth, 6o - 3oo pulses/min. The receiving system (Krupp-Atlas Elektronik, Germany) was the same as described earlier (Tesch, 1972, 1974 a). It is equipped with a pulse filtering facility and during the tracking experiments was adjusted to a pulse duration of 4o msec although the output of the pressure sensing transmitter amounted to 2o msec. Hence the range of the transmitter was only small compared to the other transmitters used in this study which were produced with a similar power output. Affixation of the transmitter to the fish in front of the dorsal and anaesthetising was done as described earlier (Tesch, 1974 a).

As tracking vessel the 37 m long R. V. "Friedrich Heincke" was used which is better fitted for longer cruises and bad weather conditions than the 24 m long vessel of the earlier experiments (Tesch, 1974, 1974 a).

Duration of tracking for the different specimens was: No. V July 4, 1973, 8.56 to 16.32 (8 hours); No. VI July 5, 1973, 9.11 to 15.45 (7 hours); No. VII July 1o, 16.4o to July 11, 1973 (24 hours); No. VIII July 1o, 2o.45 to July 12, 7.2o (35 hours). From the overlapping tracking time for Nos. VII and VIII it is obvious that tracking of two eels occurred at the same time. In addition a third fish, a cod (Gadus morhua), not dealt with in this study has been released and tracked. This simultaneous tracking of three fishes was possible because of a more stationary behaviour of two of the fishes. The weather was clear with wind not stronger than force 2 during tracking courses V and VI; it was overcast during trackings VII and VIII with winds force 1 to 5. The surface water temperature was approximatly 18^{o} (during all tracking experiments).

Net swimming direction and speed were determined as calculated earlier (Tesch, 1972, 1974 a). Direction and speed of current during tracking experiments V and VI were provided by measurements of the light ship "Deutsche Bucht"; for No. VIII values given by Neumann and Meier (1964) were used. For No. VII no positions throughout the course were available. Hence only the connection between releasing point and last tracking positions delivered the swimming direction. This seems to be sufficient for a directional evaluation as this fish could be tracked for almost two tidal periods (24,3 hours). Fig. 1 presents the calculated swimming direction for each quarter of an hour for eels Nos.V, VI and VIII by the small arrows in the circles. The mean swimming direction resulted from calculation of the mean angle on the basis of these single values. The mean direction of all specimens is examined for significance by the Rayleigh test (Batschelet, 1965).

Results

All four eels of the July 1973 used in this tracking experiment generally preferred a South-east swimming direction although from the true track this is not quite obvious (Fig. 1). The general directions taken by 4 fishes were 134.5°; 132.4°; 147.o°; 147° respectively with a mean of 14o.3°. Yellow eels in previous experiments in 1972 (Fig. 1) preferred 1o8.7° not very different from that found by Tesch 1973. Although the 1972 specimens originated from a home area which was located further south than that of the 1973 yellow eels they preferred a more northerly course. Because of the small sample sizes this might be a chance difference. If the data from both experiments are pooled (Fig. 2) the mean direction of the eight specimens is 125.5°. By application of the Rayleigh test the value of z is 6.45o and is far above the critical test value zp (= 4.2o1; error = 1 %) and the concentration in the observed direction significant.

Calculated swimming speeds for eels No. V, VI and VIII were o.696, o.74 and o.98 kn respectively. The swimming speed of No. VII could not be determined as just mentioned. At the end of the tracking it swam o.95 kn. No. VIII, which was tracked from 2o.45 to o7.2o hours the next day but one became stationary after 5 hours (1.4o) and was abandoned 3o hours later. The speed of the 1973 tracked eels was below the average displayed by yellow eels investigated 1972(Tesch, 1974 a) which swam about 1.2 kn on average.

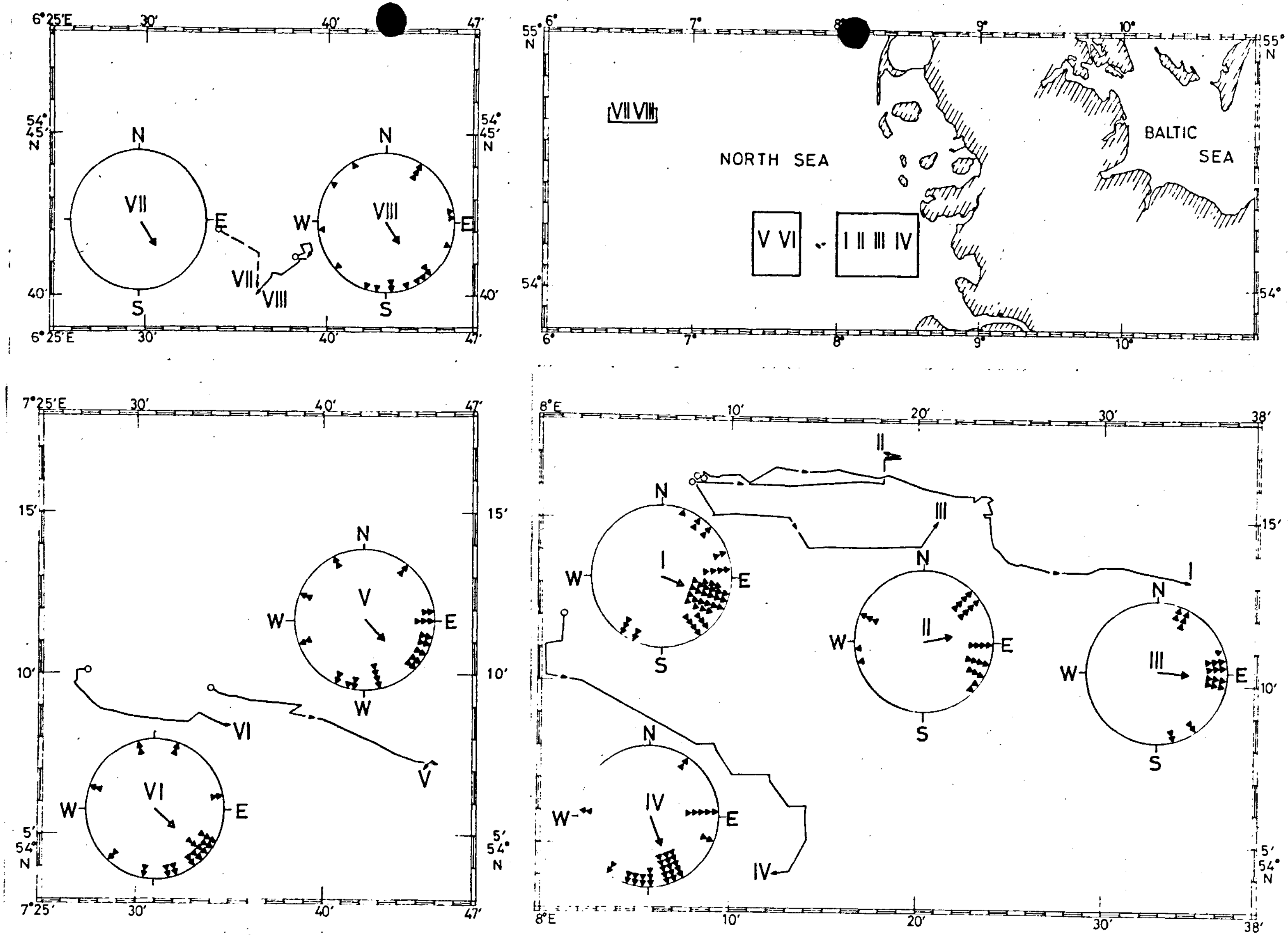

Fig. 1 Tracking courses of yellow eels (Anguilla anguilla) including calculated swimming direction and survey map with tracking areas in the North Sea (right above). Roman numbers: eels Nos. I - VIII (I - IV from Tesch, 1974 a); small circles: point of release; triangles in the compass circles: swimming direction of eel through the water calculated every 15 min; arrow in centre of the compass circles: mean swimming direction; dashed tracking course (eel No. VII): single positions during tracking not know.

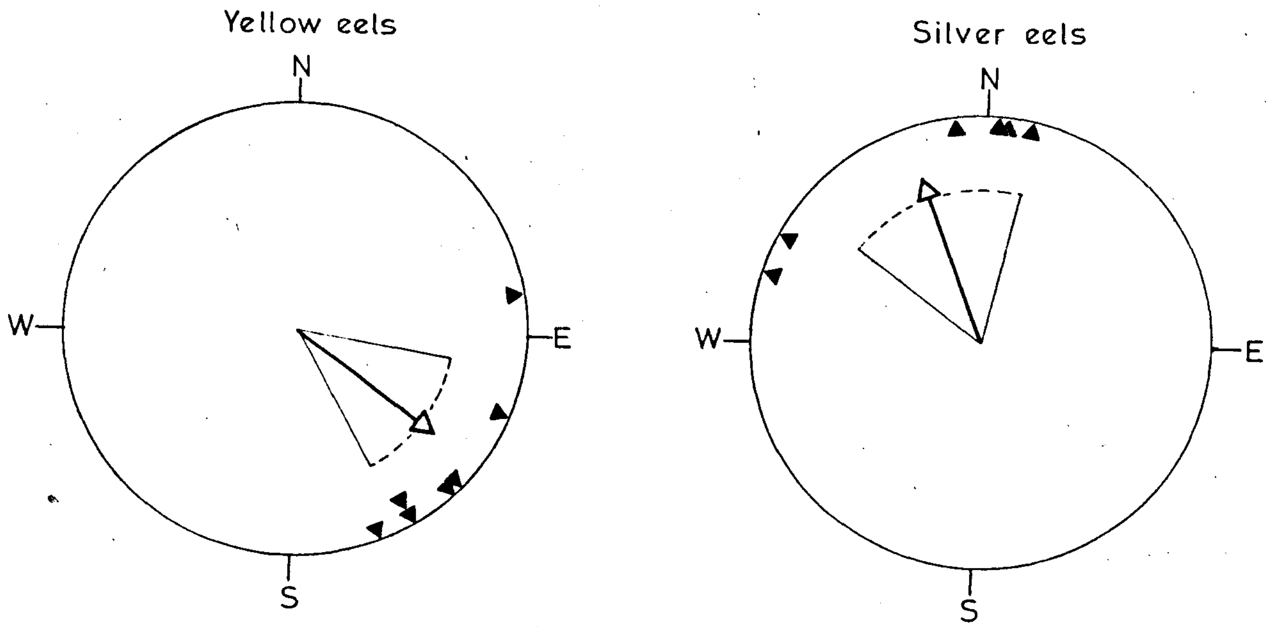

Fig. 2 Mean swimming direction (arrow) of the eight tracked yellow eels (left) compared with the mean swimming direction of six silver eels (right; after Tesch, 1974 a). Triangles: swimming direction of the single eels; hatched lines: enclose the mean angular deviation of the circular distribution.

The preferred swimming depth of No. VII as indicated by pressure sensing transmitter has been observed to be in upper water layers (Tab. 1). Only during the first minutes after release did the fish swim in medium water layers. Observations took place at day light with the sky overcast.

Discussion

The observations on the directional behaviour of displaced yellow eels in the open North Sea have confirmed earlier observations (Tesch,1974 a) that a SE compass course is taken. It now can be assumed that the eels do not migrate in the direction of their home area, which would require a more complicated mechanism of orientation, e. g. determination of longitude and latitude. Although the specimens used in this study originated from an area North of the releasing point, the tendency has not been affected. Conventional tagging experiments (e. g. Tesch, 1967) which seemed to proove immediate leading of the homing yellow eels into the direction of the home area were probably partly misinterpreted under the presumption that the eels' compass course pointed by chance in the direction of the home area. This would also be true for results of earlier tracking experiments (Tesch, 1974) with yellow eels I and II.

Analysis of the earlier long distance transplantation experiments with yellow eels tagged conventionally (Deelder and Tesch, 197o), in view of above described observations, now renders explicable results: e.g. eels displaced from the IJsselmeer dike to Helgoland (237 km NE) were

Tab. 1 Swimming depth of yellow eel No. VII at the start of its course and at the end of the tracking experiment 24 hours later. Water depth: 41 m

date	time	swimming depth (m)
July 1o	16.4o	11
	16.43	18
	16.46	4
July 11	17.oo	9
	17.11	8
	17.15	7

recaptured 1968 5o % and 1969 86 % South-East of Helgoland; eels displaced from the IJsselmeer dike to Borkum (144 km NE) were recaptured 1969 73 % southern to eastern off Borkum (Fig. 4 and 7). The homing direction in all three cases was South-West. If the home area were situated far distant east of the displacement point recaptures have been reported nearly 1oo % east to South-East of the displacement area (Fig. 8 and 9).

The fact that also yellow eels and not only silver eels have a sense for a compass direction (Fig. 2) has been supported by laboratory investigations (Tesch and Lelek, 1973). In a circular tank the yellow eels preferred either south or north directions. Hence, if an eel is moved from a Northern area to Southern releasing point it might also migrate into a Northern direction. Otherwise homing of yellow eels from the Elbe estuary to Helgoland would have been impossible.

Our results are in accordance with behaviour exhibited by other displaced stationary fishes, e. g. Abramis brama, examined during field experiments by the float-tracking method (Poddubnyi, 1965). Of the displaced breams 87.5 % moved along the magnetic meridian, of the non-displaced individuals only 5o %. Perhaps an eastward or northward orientation is a feature displayed also by spawning populations of the North American cutthroat trout (Salmo clarki):" the ability to maintain a constant compass direction until shore or bottom is available for cues and then paralleling the shoreline would be a considerable improvement over random search in homing from open water points . . . ." (McCleave, 1967). In the described manner the compass course swimming is also useful as far as homing of displaced yellow eels is concerned.

How orientation works if the shoreline or the upper littoral is reached cannot be a matter of investigation in the North Sea costal areas. Tracking on the flat tidal area with the kind of vessel used in this study is impossible and smaller vessels are not fit for the North Sea. In the 1972 yellow eel tracking experiments (Tesch, 1974 a), when eel No. I reached the littoral zone, it chose a trench for further South-Eastern movement, confirming, in addition to the experiment with the pressure sensing transmitter, that a depth not less than 4 m is preferred. A silver (migratory) eel tracked in the littoral area of Helgoland preferred a trench as well (Tesch, 1972) and did not leave areas with water depths less than about 7 m. Similarly silver eels, marked by surface floats, exhibited movements along the 5 m isobath in Kursk'lagoon of the Baltic Sea (Ovchinnikov, 1971). Hence homing yellow eels during daylight seem to be deflected from the coast by depth less than 4 m, while silver eels seem to prefer still deeper water. The release for a change in swimming direction might be bottom contact and the sensing of depth pressure or irradiance dependent. Tracking experiments along coast lines during daylight and in darkness and the application of pressure sensing transmitters could assist to answer these questions.

The exhibited behaviour of eel No. I (Tesch, 1974 a) - to swim in a deep channel - would not have led that specimen to its home area in the Elbe estuary but to a different estuary located farther North. As we know from tagging experiments (Tesch, 197o; Vladikov, 1971), transplanted yellow eels avoid foreign estuaries but succeed to find their home estuary. Hence additional orientation mechanisms must be involved. Similarly as in salmonids the smell of the home river could play a role in homing yellow eels although in this respect earlier investigations (Tesch, 197o) gave no positive results.

It is astonishing that homing yellow eels, which usually are bottom animals prefer upper water layers during migration. But the small amount of available observations has to be confirmed by further investigations. Also silver eels prefer upper water layers as shown by pressure sensing transmitters (Stasko and Rommel, 1974; Tesch, unpubl.) although frequent diving of silver eels into greater water depth, partly to the bottom, seems to indicate different behaviour compared to yellow eels.

Only one of the eight tracked yellow eels stopped its migration and obviously took to the bottom for more than thirty hours. After that time observation was discontinued. Yellow eels transplanted over long distances, forced to swim for a long time through a very monotonous environment, perhaps stop once and settle down, adapting to the new environment.

Possible stimulation responsible for compass course swimming has been investigated on silver eels by laboratory experiments (Tesch,1974 a). From the results it seems obvious that the geomagnetic field is responsible and it does ~~not~~ appear from the present study and earlier investigations on the directional behaviour of silver and yellow eels (Tesch and Lelek, 1973) that there exist many similarities in these forms of Anguilla spec. as far as their orientational behaviour is concerned. Hence also the ability of keeping compass direction by means of the geomagnetic field seems to be a capacity of yellow eels.

Summary

1. Four yellow (stationary) eels (Anguilla anguilla L.) were transplanted from Northern Danmark to the German Bight and to the central North Sea about 300 km SSW of the home area. They were tagged with ultrasonic transmitters and tracked for 7 to 25 hours.

2. The mean direction adopted by the four individuals was SE (140°), away from the direction of the home area (NNE). One eel discontinued activity after 5 hours of active swimming. Combined with earlier tracking results on yellow eels a significant directional choice of 126° is calculated; it is concluded that a South-eastern or perhaps a North-western compass course is the first swimming performance of yellow eels which home, no matter in which direction their home area is located.

3. Earlier results with conventionally tagged yellow eels transplanted over long distances have shown a South-eastern trend as well and are now explainable.

4. With a mean migratory speed below 1 kn (1.85 km/h) the experimental specimens moved slower than individuals tracked one year before in similar experiments.

5. One yellow eel tagged with a pressure sensing ultrasonic transmitter got lost twice because of an insufficently adjusted receiver. During the first minutes of tracking it preferred a depth between 4 and 18 m; 24 hours later it swam in a depth of 7 to 9 m. The water depth was 41 m.

6. From the discussion it becomes evident that yellow as well as silver eels prefer trenches if water depth decreases. Upon arrival in ihshore waters directional behaviour in yellow eels probably might change; at daylight a minimum water depth of about 4 m is preferred.

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