International Council for the
Exploration of the Sea

C.M. 1963

Near Northern Seas Committee
No. 12 C

Attention Symposium on the
Measurement of Abundance of Fish
Stocks.

The Diurnal Activity Pattern of the Sole

by

H. Kruuk

Fisheries Laboratory, IJmuiden

Introduction

The trawl catches of sole show a well-known daily periodicity with high catches at night and low catches during the day. Graphs of this periodicity have been given by Boerema and Stam (1952). What is the cause of this phenomenon? Can the sole actively escape the net during the daylight hours, or does it hide in the sand at that time; or is it perhaps swimming in higher water levels as long as the sun shines?

Very little is known about the behaviour of sole. In order to obtain more information on the causes of the diurnal variation in the catches, a great number of stomach contents has been analysed. Further, observations and experiments were made in an aquarium of 2 x 1 x 1 m, and in some smaller tanks. During the day the tanks were either kept in normal daylight, or artificially illuminated. At night a faint red light was burning, just sufficient to observe the animals.

Behaviour. Aquarium observations.

The aquarium observations revealed that during the daylight hours all sole are hiding in the sandy bottom, just below the surface. Only the mouth, the opening of the nose, and the eyes remain visible. When it is getting dark, the body of the fish suddenly undulates, and this is usually followed by a quick and strong "jump" of the fish, which describes the shape of the Greek letter Ω ("Omega-jump"). This movement removes all sand of the fishes' back. After this, the sole moves around searching for food. At daybreak it hides again, moving the sand over its body with the aid of its long dorsal and anal fins.

In order to obtain more detailed information on the sole's activity pattern in the course of 24 hours, a system of automatic registration of its movements has been used. Small lead balls were hung just above the bottom of the aquarium, in such a way that if a ball was touched and slightly displaced, the suspension thread closed an electric circuit above the water level. Each time a ball was touched, this was registrated on a kymografion. Direct observation showed that the soles did not react to contact with the lead balls, and did not try to avoid them. Figure 1 shows the result of a serie of registrations in the months of January and February 1960. The activity of the soles is greatest shortly before midnight, and decreases till zero around noon. This activity curve corresponds very closely to Boerema and Stam's curve (1952) of the diurnal variations in the sole catches in the same months of the year.

Observations on feeding periodicity

In order to determine the time of the day at which the sole is feeding complete intestinal tracts were collected from soles, caught in the trawl at various hours of the day (in August 1960). It appeared from these samples that the percentage of soles with food in their stomachs increased from about sunset till midnight, and decreased thereafter to a very low percentage in the afternoon, whereas the percentage of soles with food in the last section of the intestinal tract decreased from about midday till midnight and increased from midnight till midday (Figure 2). The middle part of the intestinal tract gave an intermediate picture.

These results show that feeding takes place mainly during the night hours, with a peak around midnight. The qualitative composition of the food differed largely between samples, but was not related to the time of the day.

Observations on the stage of the digestion of Ammodytes marinus, a common food organism of the sole, indicated that in the soles caught during the day digestion had progressed further than in soles caught during the night, which, although the differences were not very marked, supports the conclusion that sole feeds mainly at night.

A few experiments with soles in the aquarium, fed with Arenicola marina, gave diverging results, but the general picture was that this food passes through the whole digestive tract in about 18 hours or less. This again supports the above conclusion.

Activity and light

Both "omega-jump" and digging in take place during rapidly changing light intensities. The question arose whether there is a direct relation with a given light intensity.

Experiments showed that soles kept in the dark for some time, and then exposed to slowly increasing light intensity (speed of increase about the same as at daybreak), suddenly showed the digging-in movement. If no sand is present, the movement is repeated many times, for over an hour. As soon as the upper side of the fish is covered with sand, the movement stops.

If the light is diminished at a later time than the normal time of dusk, the sole performs its "omega-jump" later also, at the time the amount of light has decreased to a low level. The "omega-jump" is carried out only by animals with sand on their upper side.

Three experiments were made in which from noon onward the aquarium was kept in the dark for a period of 48 hours. The movements of the soles were registrated in the way described above. The periodicity in the activity of the soles was maintained, but the period became shorter. The first mode of activity appeared at around 21.^{h}- the next day this mode lay at 19.^{h}-, whereas as has been shown in Figure 1 the mode normally lies around 23.^{h}-. Furthermore, a fairly high activity occurred throughout the whole day, although at a distinctly lower level than that of the modes. Some direct observations showed that the animals did not dig in at all throughout these experiments.

In the reversed experiment, with four days of continuous light of an intensity such as normally is found at the sea bottom during daytime (about 100 erg./cm^{2}/sec), there was only one period of activity, after two days illumination, whereafter the activity dropped again to about zero.

Finally, an experiment was carried out in which the aquarium was artificially illuminated from 6.^{h}- till 12.^{h}- and from 18.^{h}- till 24.^{h}-, and kept dark in the periods in between, this during eight consecutive days. The results are shown in Figure 3. In both periods of light, the fish were inactive, in the periods of darkness active. Furthermore, the activity in the dark period during the night hours was distinctly higher than in the dark period from 12.^{h}- till 18.^{h}-.

It must be concluded from these experiments that light is the main factor governing the diurnal variation in the behaviour of the sole. However, an internal periodicity of the fish must play a part also, as is shown by the experiments in continuous darkness and in the experiments with a 12 hours periodicity.

Diurnal variation in the trawl catches of soles

It has been shown in the previous sections that soles move around during the night and are hidden in the sand during daytime. Apparently the fish is more easily caught when it is moving. In order to see how sole reacts to objects moving along the sea bottom, an iron bar with small cross-bars was pulled over the bottom of a large aquarium with soles, this during daytime. It appeared that it is very difficult to chase sole out of the sand with such an instrument, even if the fish was hurt by the cross-bars. Even when trying to lift a fish out of the sand by means of a long stick, it was very hard to succeed in getting the animal to swim. If, however, the sand was removed from the upper side of the sole, the fish often swam away, or dug in again immediately.

These preliminary observations suggest that a trawlnet with or without tickler chains cannot catch soles efficiently during daytime.

Conclusions

1. Soles move around and feed at night, dig in at daybreak and remain inactive until dusk.
2. This periodicity is mainly governed by light intensity, but an internal rhythm also plays a part.
3. Fish which are hidden in the sand during daytime, are very hard to drive up.
4. This behaviour pattern is the cause of the diurnal variation in the trawl catches of sole.

Reference

Boerema, L.K. and Stam, A.B. 1952 "A preliminary note on the sole in the Dutch coastal area". ICES, C.M.1952, Near Northern Seas Committee.

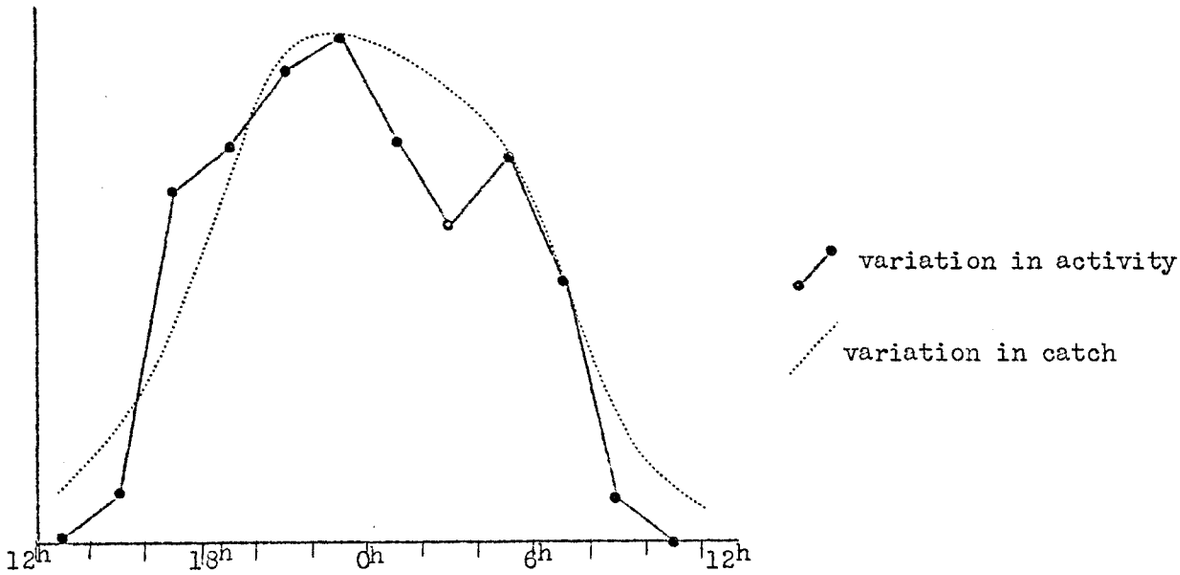

Figure 1. Diurnal activity of sole in an aquarium in January-February (full line), and diurnal variation in trawl catches in the very same months (after Boerema and Stam, 1952), (dotted line).

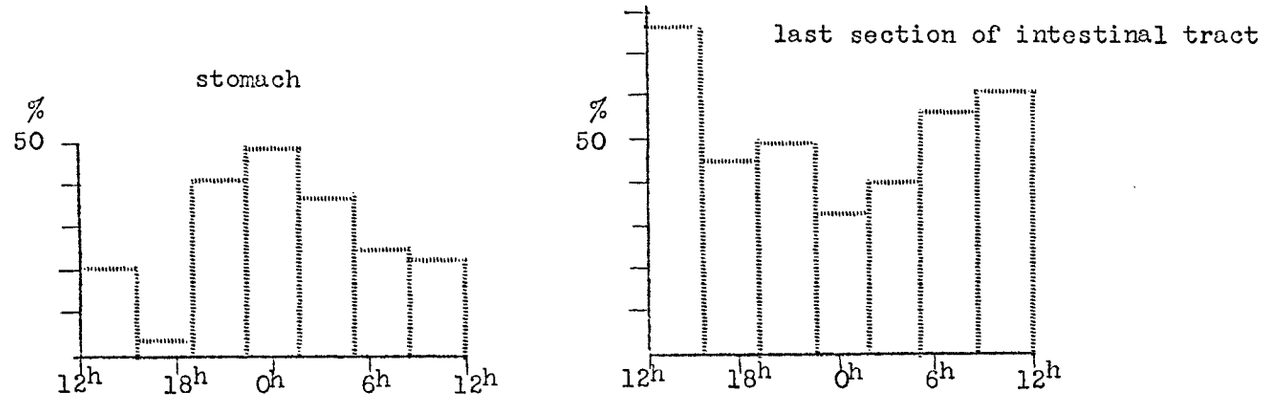

Figure 2. Percentage of soles with food in the stomach (A), and in the last section of the intestinal tract (B) at various hours of the day.

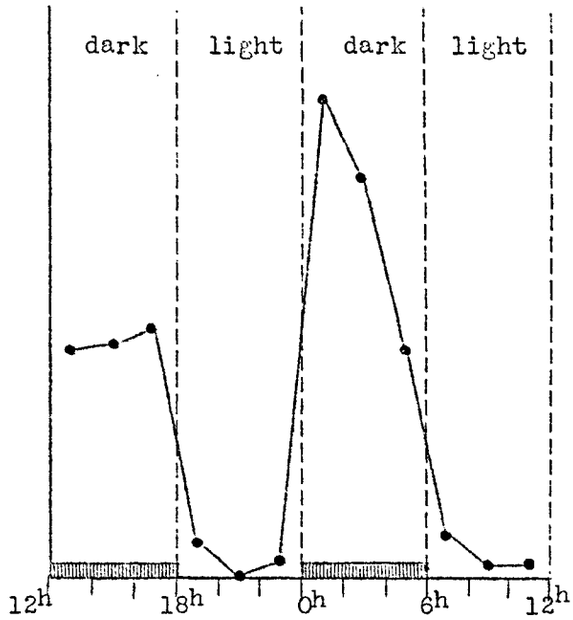

Figure 3. Activity of sole in an aquarium with alternatingly 6 hours of light - 6 hours of darkness.