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THE CONSEQUENCE OF MARINE GRAVEL EXTRACTION FOR THE SPAWNING OF HERRING.

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Abstract

The rapid increase of the mining for marine gravels in the North Sea offers a serious threat to the marine environment and especially for the herring populations of the southern North Sea and Channel. The paper reviews the literature dealing with the herring and its spawning ground, behaviour, abiological characteristics - type of substrate, depth, salinity, temperature, current velocity. And a hypothesis is put forward that sound may play an important role in guiding the herring to its spawning site.

Introduction

The herring takes in several respects a special position amongst the important commercial fish species. In the first place as it deposits its eggs upon the sea-bottom attaching them to gravelly material or seaweed. To day the herring is heavily overfished and all attention of fishery biologists is focussed on the measures for an adequate stockmanagement. This might side track the attention from another threat to the survival of the herring (viz.) that of the activities of the marine gravel industry, notwithstanding that already in 1974 the ICES Working Group on Effects of Marine Sand and Gravel Extraction pointed out this danger (Anon., 1975).

There is a constant demand for gravel for the large conurbations, bordering the southern North Sea such as the London and Rotterdam areas. It may be discussed how large the need will be in the near future, the fact remains that gravel extraction is depleting a non renewable source. From intensive geological mining surveys we know that on the Continental side of the North Sea there are no deposits of gravel comparable with those on the English side. The inland gravel resources of the Netherlands will be exhausted within a period of 25 years from now. In respect to the British gravel resources in the southern North Sea, it is estimated that in order to satisfy the demand for gravel of the London area, alone, marine gravel will no longer be available for export within 50 years from now (Oele, 1978). Therefore the threat of the marine gravel extraction in the southern North Sea to the survival of the already too far depleted herringstocks is far from hypothetical. The present paper tries to review the available data bearing on the relation herring and its spawning grounds. It is striking that notwithstanding this relation is known from about 1803, when Walker stated that herring deposits its eggs on a selected gravelly bottom at about 10 - 12 fathoms so little came to light how the herring selects its spawning ground (McIntosh and Masterman, 1897). A hypothesis is formulated here that herring may use sound characteristics of the sea bed under the actions of the underwater currents as a clue to recognize their spawning site in addition to the total homing behaviour described by Harden Jones (1968). Altering the sea bed as a consequence of gravel extraction may negatively influence the migration, and the survival, of the herring-stocks in the southern North Sea.

The relation between spawning herring and substrate.

It was mainly the activity of Allman, who studied in 1862 the herring of the Firth and Forth, that the attention again was focussed on the relation between the spawning of herring and the type of substrate. He discovered abundance of spawn on rough rocky ground near the Isle of May in depths from 25-40 m. The eggs were attached to stone shingle, shells and other objects on the sea bottom (Cunningham, 1896).

Ewart (1884) studied the now very well documented herring spawning ground on the Ballantrae Bank in the Firth of Clyde. Here the spawn is deposited on flat areas covered with coarse sand and gravel (see below Parrish et al. 1959; Hemmings, 1965).

Jenkins (1927) states also that herring on the eastcoast of Scotland prefer hard ground covered with Hydrallmania (Allman!) and other Hydrozoa. He moreover briefly mentions spawning of herring on the banks of the river Schlei (Baltic) and in various bays in the neighbourhood e.g. Eckenforder Bucht. Also the stony slopes of the Kiel Canal where the herring spawned on stones covered with algae (seaweed?); off the island of Fehmarn (Baltic) and off Sylt and Rom (North Sea) and in the shallow waters of the Zuiderzee (now Lake IJssel).

Redeke (1907) described the spawning areas in the Zuiderzee near the coast between Edam and Volendam as well the shallow banks south of the Island of Urk, the Knar and the Enkhuizer Sands. Here between April and June the eggs were deposited on shingle, seaweed and other seaplants.
Jenkins summarizes the characteristics of all these spawning grounds as follows: "they are always clean and firm, never shifting or covered with mud".
Today Runnström's work is still the best and most thorough attempt to study the spawning of herring, he investigated 14 spawning grounds off southern Norway. He found "that the bottom on the spawning grounds was composed of rocks, stones, gravel and sand but also to a great extent of calcareous deposits of broken shell, serpulid tubes, calcareous algae etc. forming a more or less coarse shell sand.

Also brown and red algae may be found covered by roe and even free-living animals as Hyas and other species have been caught with herring eggs attached to the body!!
Of the bottom grab samples taken, nearly 49% of those containing eggs; 41% were obtained on rocky bottom while 34% of the samples contained algae, gravel or shell. On fine sand bottom herring eggs were found in only 18%.
Bolster and Bridger (1957) described a typical Downs herring spawning area in the English Channel (Sandettie). They found that spawn was generally attached to flints, 2.5 - 25 cm in length where these occurred over gravel. The heaviest concentration was found within an area 3.5 km long and 400 m wide. The long axis of this narrow strip lay in line with the main direction of the tidal current. Parrish et al. (1959) surveyed the spawning bed in the Firth of Clyde already described by Ewart (1884). They used dredge, grab and photographic surveys to map the patch of eggs on the sea-bed. The patch was about a square measuring 320 x 320 m. The boundary of the egg patch coincided with a change from gravel and small stones to large stones and rocks. The eggs were distributed in an almost continuous carpet.

Tibbo et al (1963) investigated the spawning of herring with free-diving techniques. They surveyed a herring spawning bed near Blanchard Point N.B. (Canada). The eggs were found on algae and hardly ever on bare stone. The bottom consisted mainly of small stones and gravel with large masses of red sandstone.

Hemings (1965) also made underwater observations on a patch of herring spawn in the Firth of Clyde (Ballantrae Bank). He observed the herring spawn lying as a carpet on fairly coarse gravel of uniform size. Also that herring select not only the right size of gravel on which to deposit their eggs, but also the crest of a ridge instead of the hollows.

Bowers (1969) studied two spawning beds of Manx herring by means of a grab survey off the east coast of the Isle of Man. The spawning beds were small (approx. 200x100 m, 100x60m). The herring eggs formed again a continuous carpet on a substrate of course gravel, small stones and shell.

Dragesund (1970) located the spawning grounds of Norwegian spring spawning herring by studying the geographical distribution of catches of spawning and spent herring, and also by the occurrence of newly hatched larvae. He was not able to locate the spawning grounds exactly, however the spawning was restricted to grounds with sandy or rocky bottom.

Iles and Caddy (1972) surveyed with a submersible the herring spawning on the Georges Bank, (off Boston, USA). They located the egg beds on a flat gravel-covered plain on the bank at a depth of 50 m. The gravel was rounded, varying in particle size from 0.5 - 5 cm to cobbles from 8-15 cm and also boulders, partly embedded in the substrate were found. The eggs formed a firm and cohesive layer of

1 to 2 cm thickness over the substrate. Although the eggs were found only on level gravel and around 50 m depth they could establish that only a fraction was being used for spawning. They state that some localities might be distinguished by subtle topographic and hydrographic features which serve to guide the herring to their home spawning grounds. Also they observed clouds of newly-hatched larval herring floating just above the bottom, drifting with the current.

Drapeau (1973) also studied the sedimentology of the herring spawning grounds on Georges Bank. He found that herring spawned on a gravel bottom in a high energy environment. Herring spawn was only observed on gravel patches devoid of sand at an average depth of 40 m in an area where tidal currents reach an intensity of 1 m/sec and storm wave oscillations on the bottom exceed 70 cm/sec.

Dorel and Maucorps (1976) made an attempt to correlate the sedimentologic characteristics of the substrate with herring catches and hydrological data of the Downs herring spawning grounds in the Channel and Seine Bay. Despite the lack of herring eggs among the dredged sediments during their survey, they could distinguish three spawning areas. The average composition of the sediment was boulders 42.2%, gravel 34.0% and sand 23.8%.

"Spawny" haddocks

In the days of plenty when herring spawn was abundant off the Scottish east coast, the trawl fisherman looked for haddocks feeding on the herring eggs. The line fisherman met with success as their baited hooks lost all attractiveness for the haddock (Cunningham, 1896). The haddock feeding on this unusual food could be easily distinguished from fish which fed on a more normal diet, being plump and with a characteristic bloom on the skin, which masks the dark pigment.
It was Bowman (1923) who recognized the "spawny" haddock as a tool to delineate the extent and location of herring spawning grounds. He was able to point out roughly many of the spawning grounds of herring around the coasts of Scotland, by sampling daily the fishmarkets and asking the fisherman where they caught their "spawny" haddocks.
He could establish that spring and autumn spawning may take place on approximately the same grounds.

Fridriksson and Timmermann (1951) also tried to trace with "spawny" haddocks the herring spawning grounds off southwest Iceland. They found, based on haddock stomachs that herring spawned on dark coarse sand and gravel and that the eggs were being glued to the largest particles.

THE ABIOTIC CHARACTERISTICS OF THE SPAWNING GROUND

Depth

The depth doesn't seem to play a too important role as herring was able to spawn with success in very shallow water (Zuiderzee, Kiel Canal, Schlei) as well as in 90 m deep water off southern Norway. As an average a depth of about 40 m is often observed(e.g. Ewart, 1884; Redeke, 1907; Jenkins, 1927; Runnström, 1941; Drapeau, 1973).

Temperature

Temperature plays an important role as was demonstrated by Jean (1956) in his comprehensive study on the spring- and autumn spawning herring at Grande-Rivière, Bay of Chaleur, Quebec. He compared the mass of data collected on water temperatures during spawning and also refers to data from the North Sea and Channel. Scattergood, Sindermann and Skud (1959) studying the Pacific and Atlantic herrings of North America only, showed that herring spawns over a wide range of temperatures. The herring which spawn on the gravel beds near Shields (North Sea) seem to avoid grounds where the temperature during the spawning period drops below the 10 - 14°C.

Experiments by Blaxter (1956) and Blaxter and Hempel (1961) indicated that temperature conditions on the spawning grounds during the spawning time may well be one of the factors directly controlling the success of recruitment. This was substatiated by Postuma (1971) and Postuma and Zijlstra (1974). They analysed the catch data of spawning herring of the Dogger Bank, Downs and Eastern Channel. They calculated the recruitment strength as at three years of age of the different year-classes. This was compared with bottom temperature data at time of hatching. They could demonstrate e.g. that the temperature conditions on the spawning grounds affected year-class strength, possibly through differential egg mortality at different temperatures.

Salinity

It doesn't seem to be too important either as herring spawns in very brackish water with salinity of 10-15 g/kg till 35 g/kg. It is likely that again each herring population has its own preferences. The coastal herring races show a greater adaptability to various salinities than the races from the open sea.

The substrate

From the reviewed literature it is obvious that during more than hundred years most of the fisheries biologists were satisfied when they could locate a spawning ground, which is in it self no mean feat. The fact that herring stick their eggs to stones, gravel, shingle, pebbles, shell, seaweed etc. by an adhesive mucus produced in the ovary is also well described. Sometimes the observation that herring spawned on algae or seaweed, or just didn't, is often over emphasized.

Spawning on sea-weed accentuates the environmental requirements of the herring, as sea-weed only survives and grows in clear, transparent water with a high current velocity. The now extinct brackish water herring population of the former Zuiderzee of the Netherlands spawned on a bank, the Knar, covered with sea-weed. But also the fyke-nets and poles on this bank fulfilled the requirements of a suitable substrate to attach the eggs.

Currents

It was Drapeau (1973) who pointed out that tidal currents on the spawning site reach an intensity of 1 m/sec and that wave oscillations on the bottom exceed 70 cm/sec. He states that the spawning in a high energy environment probably serves two purposes. The strong currents prevent the siltation of fine sediment that could hinder the eggs from sticking to the gravel and could also smother the eggs during the period of incubation (Hildebrand, 1963). Furthermore the sea-water circulation over the spawn removes the metabolites and supplies the oxygen necessary for successful hatching (Hempel, 1971).

The migration near the spawning ground

However, not only the fact that herring spawns on gravel is of importance, but also that in a gravel area they select certain specific beds year after year. Harden Jones (1968) reviewed the phenomenon of the return to the parent spawning ground and bed. And he concludes that it is fair to acknowledge the evidence for the hypothesis that the majority of recruits spawn on the parent ground. But the data are not conclusive, and it will be difficult to prove, if at all, that recruits are survivors of a particular group of larvae hatched at a certain spawning area.

It will also be very difficult to detect how the herring returning on the spawning ground recognizes the old spawning (hatching) site. It is known that the sand and gravel ridges of the Channel have their own specific noise characteristics, and this will apply to other banks just as well. When listening with hydrophones close to the bottom the change of the tides can be heard when the water currents flow over the gravel beds from one direction to another, with a relatively silent interval during the slack tide. Each bottom sediment type, but also each individual shingle bank has its own specific noise spectrum. Herring possesses very good hearing capabilities and very likely are able to discriminate the direction of the sound source. Besides acoustic localization in herring has been proved. This was demonstrated by Enger and co-workers during the last decade (e.g. Enger, 1967, 1969; Olsen, 1969, 1976). The significance of sound in the life of fish is still only very poorly understood. It was established, however, that herring is sensitive to pure tone and noise signals within a frequency range of 30-5000Hz. Usually signals in the low frequency region (<500 Hz) evoke stronger responses than higher frequencies. Responses to low frequency signals were observed at sound levels ranging from 20 to 30 dB above the spectrum level of the background noise. The degree and duration of the motional response of the school does not seem to depend solely upon the level of the acoustic stimuli, but also on the presence of other natural stimuli, such as e.g. availability of food organisms and presence of water currents, as stated by Olsen (1976). It is put forward here that herring may use sound characteristics of the sea bed under the actions of underwater currents as a clue to recognize their spawning site. This in addition to the total homing behaviour described by Harden Jones (1968), to some extent based on the work by Zijlstra (1958, 1969).

The result of gravel dredging, will in many cases be an appreciable increase of the local depth, and this will lower the mean tidal current. The noise spectrum is a composition of several sound sources. The alteration of the tidal currents is the main source, however, noise is also evoked by the eddies which occur when the waterflow passes the gravel. The rolling of gravel smaller than 6 mm may also possibly add to the specific noise spectrum. The modulation of the frequency of the sound by the penetration of the horizontal movements of the surface waves will decline rapidly with depth, thereby altering a clue to recognizing the spawning site.

The production of specific noises by banks is to some extend analogous to eolic sound produced at certain beaches ("whispering sands"). The lower speed of the currents in water and the different properties of the medium cause similar phenomena to be lower pitched in water than in air. This shifts the spectral components of the sound in the frequency range for best temporal analysis and acoustic localization in fish (here the herring). This is relevant because the sounds may not only be used for (non-directional) recognition but may in addition serve as steering stimuli. Recent studies indicate that there is no distance range to acoustic localization in fish provided the particle motions in the sound exceed the (masked) treshold (Schuijf and Buwalda, 1979).

It is described by Runnström (1941) that there is a close relation between herring above their spawning ground and sudden changes in salinity and temperature causing their disappearance from the banks. He points out that unperiodical changes in the meteorological conditions may cause great shifts of the watermasses, suddenly altering the conditions for the spawning immigration to the coastal grounds. These layers of water with different hydrographical characteristics might interfere with the steering stimuli the herring recieves from the spawning ground by obscuring the sound signals from the bottom.

Discussion

From what is mentioned above, it is likely that altering the structure of the spawning ground of herring may affect the stocks in a negative way. This may be caused by the fact that herring in spawning condition are unable to locate their spawning site used by them for several generations. They will shed their eggs on less than optimal sites in the vicinity. As of consequence of this it may have its repercussions on the successful reproduction. It is fully understood that there are several critical stages in the life of herring. However, why they are selecting specific areas on a shingle bank to spawn is still not well understood. It is likely that many factors are involved as temperature, sound, bottom current velocity, the absence of siltation, depth. There is still a gap in our knowledge of herring behaviour. It is also likely that spawning areas are more extensive when spawning stocks are large than they are small. After hatching of the larvae the availability of suitable food on or near the spawning ground is presumably the most important environmental factor controlling the year-class strength next to temperature and predators. A decrease of the transparency of the water near the bottom caused by dredgers might hinder the vision of the still poor swimming larvae in search for food and hence endanger their life. Fine silt may adhere itself to the gill of the larvae causing suffocation. In this respect it is interesting to note that adult herring will try to avoid suspended sediments from dredge activities. For fine sediment of 4.5 median particle diameter the treshold concentration is 19 ± 5 mg/L and for coarser sediment containing 30% sand it is 35 ± 5 mg/L (Wildish, Wilson and Akagi, 1977).

One should investigate what will happen to a known spawning area if part of the sediment (gravel and sand mixture) is dredged away. Will the herring adapt itself to the change in environment, or not at all. Will we get a repetion of what happened to the former Zuiderzee-herring. A typical coastal herring race inhabiting this water from about the mid 15th Century, when the Zuiderzee originated more or less to its present shape. It is fully understood that the coastal herring population shows presumably a greater adaptation to changing environmental factors as salinity and temperature then the typical North Sea races, the autumn-spawners.

In 1546 herring was caught near Amsterdam in almost fresh water, together with eel, bream, roach and ruffe (Deelder and Huussen, 1973). What happened to this typical brackish water herring is an example how persistent herring on its way to the spawning grounds can be. The Zuiderzee, a bight of the North Sea, was closed off by a dam construction (Afsluitdijk) in 1932. Biologists predicted that as these herring spawned in the Zuiderzee, this would be the end of the existence of this population; it would die out in a natural way from the lack of offspring. Fishermen would not believe this hypothesis. The following six years the herring came back to spawn, but, they could not enter the now fresh-water lake called IJsselmeer. They spawned on the rocks and boulders forming the seaward underwater protection of the dam, where the spawn was washed away and destroyed by the wave action. The catches the first years were still high, but dropped from 15.000 tons in 1932 to 12 tons in 1939, when the commercial fishing ceased. The typical Zuiderzee herring, with its specific number of vertebrae distinguishing it from its North Sea relatives, disappeared for ever (HAVINGA, 1954).

The areas indicated by the ICES Herring Working Group (Postuma, Saville and Wood, 1977) cover all the grounds where herring spawns and may spawn or once spawned. If the overfished herring populations of the North Sea are to increase again, when the international stock management measures become effective, then they should possess suitable spawning grounds. As it is very likely that gravel deposits needed for the gravel industry are within the suggested protected zones for herring a careful decision has to be made as to where the gravel may be taken and what mixture.

A c.aim to protect all the spawning areas and potential spawning of herring as suggested in ICES-report by their Herring Working Group is untenable in the light of the need of marine sand and gravel. The industry recognizes their responsibility of reaching a measure of common agreement to ensure that the climate can be created for the two industries, fisheries and sand and gravel industry, to work side by side in a harmonious manner. In their report they already mention that, "not one of our present or former licensed areas coincides with the areas shown as herring spawning grounds" (Anon., 1979). A study of herring behaviour and why they select specific areas on e.g. a shingle bank to spawn is needed. As it is also estimated that the British marine gravel deposits in the southern North Sea will be depleted within 50 years whereas the fisheries will be practised in the southern North Sea for many hundreds of years, careful evaluation at an European level is needed of the relative short term benefits for the marine gravel industry and the long term interests of the fisheries.

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