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The consequences of marine gravel extraction on the spawning of herring, *Clupea harengus* Linné

S. J. DE GROOT

Netherlands Institute for Fishery Investigations, IJmuiden, The Netherlands

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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 and current velocity. A hypothesis is made that sound may play an important rôle in guiding the herring to its spawning site.

I. INTRODUCTION

The herring occupies a special position amongst the commercial fish species. First it deposits its eggs on the sea bed attaching them to gravelly material or seaweed. Secondly the herring is heavily overfished and the attention of fishery biologists is focused on measures for adequate stock management. This might deflect their attention from another threat to the survival of the herring in the southern North Sea namely the activities of the marine gravel industry, notwithstanding 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. From 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. It is estimated to satisfy the demand for gravel in the London area alone, marine gravel will no longer be available for export within 50 years (Oele, 1978). The threat of the marine gravel extraction in the southern North Sea to the survival of the herring stocks is therefore far from hypothetical. The present paper reviews the available data relating to the herring and its spawning grounds. This relation is known from when Walker (1803) stated that herring deposited their eggs on the sea bed 10–12 fathoms deep, although it was not known why and how the herring selects its spawning ground (McIntosh & Masterman, 1897). A hypothesis is proposed that herring use the sound characteristics of the sea bed by the actions of underwater currents to recognize their spawning site in addition to the homing behaviour described by Harden Jones (1968). Altering the sea bed as a consequence of gravel extraction may influence the migration and survival of the herring-stocks in the southern North Sea.

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et al. (1959) studying the Pacific and Atlantic herrings of North America showed that spawning occurred within 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 & Hempel (1961) indicated that temperature conditions on the spawning grounds may be one of the factors directly controlling the success of recruitment. This was substantiated by Postuma (1971) and Postuma & Zijlstra (1974) who analysed the data of spawning herring of the Dogger Bank, Downs and Eastern Channel. They calculated the recruitment strength at three years of age of the different year-classes. This was compared with bottom temperature at time of hatching. They demonstrated that the temperature on the spawning grounds affected the year-class strength, possibly through egg mortality.

SALINITY

Salinity is not an important factor since herring spawn in a salinity range of 10–15‰ to 35‰. Each herring population may have its preference but offshore salinities are unlikely to vary significantly although the coastal herring races are more adaptable than those from the open sea.

THE SUBSTRATE

The literature of the past century indicates biologists were satisfied when they could locate herring spawning grounds. Herring attach their eggs to stones, gravel, shingle, pebbles, shell seaweed etc. by an adhesive mucus produced in the ovary. Spawning on seaweed accentuates the environmental requirements of the herring, as seaweed only survives in clear 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 seaweed; but the fyke-nets and poles on this bank also fulfilled the requirements of a suitable substrate to which to attach the eggs.

CURRENTS

Drapeau (1973) noted that tidal currents on the spawning site reach an intensity of 1 m/s and that wave oscillations on the bottom exceed 70 cm/s. He states that the spawning in a high energy environment may serve two purposes. The strong currents prevent the settling of fine sediment that could hinder the eggs from sticking to the gravel and smother them during incubation (Hildebrand, 1963). Furthermore the sea water circulation over the spawn removes the metabolites and supplies the necessary oxygen (Hempel, 1971).

IV. THE MIGRATION NEAR THE SPAWNING GROUND

Harden Jones (1968) reviewed the phenomenon of the return to the parent spawning ground. He concluded there was evidence for the hypothesis that the majority of recruits spawned on the parent ground although the data are not conclusive and it will be difficult to prove. It is known that the sand and gravel ridges of the Channel have their own specific noise characteristics. When

listening with hydrophones close to the bottom the change of the tides can be recognised as the flow of the currents change direction over the gravel beds; there is a relatively silent interval during the slack tide. Each sediment type, and each individual shingle bank has its own specific noise spectrum. Herring possesses good hearing and are able to discriminate the source of the sound (Enger, 1967, 1969; Olsen, 1969, 1976). It was established that herring are sensitive to signals within a frequency range of 30–5000 Hz. Signals in the low frequency region (< 500 Hz) evoked stronger responses. It is suggested therefore that herring may use the sound characteristics of the sea bed as a clue to recognize their spawning sites in addition to the homing behaviour described by Harden Jones (1968), and Zijlstra (1958, 1969).

Gravel dredging, will cause a localised increase in the depth of sea bed and lower the tidal current. The lower speed of the currents will alter the best frequency range to allow the herring to use its power of acoustic localization. Recent studies indicate that the range of acoustic localization in fish is considerable provided the specific sound particle motions exceed the background threshold (Schuijf & Buwalda, 1980). Runnström (1941) observed there is a relationship between herring above their spawning ground and sudden changes in salinity and temperature which can cause their disappearance. He points out that changes in the meteorological conditions may alter the conditions for the spawning immigration to the coastal grounds. The layers of water with different hydrographical characteristics might interfere with the steering stimuli the herring from the spawning ground by obscuring the sound signals from the sea bottom.

V. DISCUSSION

It is therefore likely that altering the structure of the spawning ground of herring may affect the stocks because herring in spawning condition may be unable to locate their customary spawning grounds and shed their eggs on less optimal sites. There are several critical stages in the life of herring. After hatching of the larvae the availability of suitable food on the spawning ground, together with temperature and predators, is important in controlling the year-class strength. As the water near the bottom is made turbid by dredgers the vision of the larvae in their search for food is impeded; fine silt may adhere to the gills causing suffocation. Adult herring try to avoid suspended sediments; the threshold concentration for fine sediment is 19 ± 5 mg/l and for coarser sediment containing 30% sand it is 35 ± 5 mg/l (Wildish *et al.*, 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? Will we get a repetition of what happened to the former Zuiderzee herring? In 1546 herring were caught near Amsterdam in almost fresh water, together with eel, bream, roach and ruffe (Deelder & Huussen, 1973). The Zuiderzee was closed by a dam (Afsluitdijk) in 1932. Biologists predicted that as the herring which spawned in the Zuiderzee would die out from the lack of offspring. The next six years the herring came back to spawn, but, they could not enter the now freshwater 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 for the first years were 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 (Havinga, 1954).

The areas indicated by the ICES Herring Working Group (Postuma *et al.*, 1977) cover all the grounds where herring spawns, 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. A claim to protect all the spawning areas and potential spawning of herring as suggested in the 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 a 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 mention ' 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 therefore needed.

References

Anon. (1975). *Report of the Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction. Cooperative Research Report No. 46.* Charlottenlund, Denmark: International Council for the Exploration of the Sea.

Anon. (1979). Reply from the sand and gravel dredging industry to the International Council for the Exploration of the Sea. In *Report of the Working Group on Effects on Fisheries of Marine Sand and Gravel Extraction. Cooperative Research Report No. 46*, pp. 1–32. Surbiton, Surrey: Marine Section of the Sand and Gravel Association Ltd.

Blaxter, J. H. S. (1956). Herring rearing—2. The effect of temperature and other factors on development. *Mar. Res. Scot.* **5,** 119 pp.

Blaxter, J. H. S. & Hempel, G. (1961). Biologische Beobachtungen bei der Aufzucht von Heringsbrut. *Helgoländer wiss. Meeresunters.* **7,** 260–283.

Bolster, G. C. & J. P. Bridger, 1957. Nature of the spawning area of herrings. *Nature* 179–638.

Bowers, A. B. (1969). Spawning beds of Manx autumn herrings. *J. Fish Biol.* **1,** 355–359.

Bowman, A. (1923). The occurrence of ' spawny ' haddock and the locus and extent of herring spawning grounds. *Scient. Invest. Fishery Bd Scotl.* **1922**, 1–15.

Cunningham, J. T. (1896). *The Natural History of the Marketable Marine Fishes of the British Islands*, pp. 150–163. London: MacMillan.

Deelder, C. L. & Huussen, A. H., Jr. (1973). Opmerkingen betreffende de kuilvisserij op de voormalige Zuiderzee, voornamelijk in de zestiende eeuw. *Holland* **5,** 221–242.

Dorel, D. & Maucorps, A. (1976). Note sur la granulométrie des frayères de hareng en Manche orientale. *ICES C. M.* 1976/H: 20 Comité des poissons Pélagiques (Nord).

Dragesund, O. (1970). Recruitment studies of Norwegian spring spawning herring (*Clupea harengus* Linné). *Fisk Dir. Skr. Ser. Havunders.* **15,** 381–450.

Drapeau, G. (1973). Sedimentology of herring spawning grounds on Georges Bank. *ICNAF Res. Bull.* **10,** 151–162.

Enger, P. S. (1967). Hearing in herring. *Comp. Biochem. Physiol.* **22,** 527–538.

Enger, P. S. (1969). Nervous responses in the fish brain to pure tones and to noise. *ICES C. M.* 1969–B: 7 Gear and Behaviour Committee.

Ewart, J. C. (1884). Natural history of the herring. *Rep. Fishery Bd Scotl.* **2,** 61–73.
Fridriksson, A. & Timmermann, G. (1951). Herring spawning grounds off the south east of Iceland during 1950. *J. Cons. perm. int. Explor. Mer* **17,** 172–180.
Harden Jones, F. R. (1968). Fish migration. In *The Herring,* pp. 86–143. London: Edward Arnold.
Havinga, B. (1954). Vissen. In '*Veranderingen in de Flora en Fauna der Zuiderzee na de afsluiting in 1932*' (L. F. de Beaufort, ed.) Report 1954 Nederlandse Dierkundige Vereniging.
Hemmings, C. C. (1965). Underwater observations on a patch of herring spawn. *Scott. Fish. Bull.* **23,** 21–22.
Hempel, G. (1971). Egg production and egg mortality in herring. *Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer.* **160,** 8–11.
Hildebrand, S. F. (1963). Fishes of the western North Atlantic, family Clupeidae, *Sears Found. Mar. Res., Mem.* **1,** 274–293.
Iles, T. D. & Caddy, J. F. (1972). Herring spawn in close-up. *World Fishing, June,* 14–16.
Jean, Y. (1956). A study of spring and fall spawning herring (*Clupea harengus* L.) at Grande–Rivière, Bay of Chaleur, Québec. *Contr. Dept. Fish* **49,** 1–76.
Jenkins, J. T. (1927). *The Herring and the Herring Fisheries.* London: P. S. King and Son Ltd.
McIntosh, W. C. & Masterman, A. T. (1897). *The Life-histories of the British Marine Food-fishes,* pp. 405–422. London: C. J. Clay & Sons.
Oele, E. (1978). Sand and gravel from shallow seas. *Geologie Mijnb.* **57,** 45–54.
Olsen, K. (1969). Directional responses in herring to sound and noise stimuli. *ICES C. M.* 1969/B: 20—Gear and Behaviour Committee.
Olsen, K. (1976). Evidence for localization of sound by fish in schools. In *Sound Reception in Fish* (A. Schuijf & A. D. Hawkins, eds), pp. 257–270. Amsterdam: Elsevier.
Parrish, B. B., Saville, A., Craig, R. E., Baxter, I. G. & Priestley, R. (1959). Observations on herring and larval distribution in the Firth of Clyde in 1958. *J. mar. biol. Ass. U.K.* **38,** 445–453.
Postuma, K. H. (1971). The effect of temperature in the spawning and nursery areas on recruitment of autumn-spawning herrings in the North Sea. *Rapp. P. -v. Réun. Cons. perm. int. Explor. Mer* **160,** 173–183.
Postuma, K. H. & Zijlstra, J. J. (1974). Larval abundance in relation to stock size, spawning potential and recruitment in North Sea herring. In *The Early Life History of Fish* (J. H. S. Blaxter, ed.), pp. 113–128. Berlin: Springer-Verlag.
Postuma, K. H., Saville, A. & Wood, R. J. (1977). Herring spawning grounds in the North Sea. *ICES Coop. Res. Rep.* **61,** 1–15.
Redeke, H. C. (1907). Rapport over onderzoekingen betreffende de visscherij in de Zuiderzee ingesteld in de jaren 1905 en 1906. Publication of the Ministry of Agriculture, Industry and Commerce, The Hague, pp. 34–37.
Runnström, S. (1941). Quantitative investigations on herring spawning and its yearly fluctuations at the West Coast of Norway. *Fisk. Dir. Skr. Serie Havunderssøkelser* **6,** 1–71.
Scattergood, L. W., Sindermann, C. J. & Stud, B. E. (1959). Spawning of North American herring. *Trans. Am. Fish. Soc.* **28,** 164–168..
Schiujf, A. & Buwalda, R. J. A. (1980). Underwater localization 'A major problem in fish acoustics'. In *Comparative Studies Hearing in the Vertebrates,* pp. 43–77. New York: Springer Verlag.
Tibbo, S. N., Scarratt, D. J. & McMullon, P. W. G. (1963). An investigation of herring *(Clupea harengus* L.) spawning using free-dividing techniques. *J. Fish. Res. Bd Can,* **20,** 1067–1079.
Wildish, D. J. & Wilson, A. J. Avoidance by herring of suspended sediment from dredge spoil dumping. *ICES C. M.* 1977/E: 11—Fisheries Improvement Committee.
Zijlstra, J. J. (1958). On the herring ' races ' spawning in the southern North Sea and English Channel. *Rapp. P. -v. Réun. Cons. perm. int. Explor. Mer* **143,** 134–145.
Zijlstra, J. J. (1969). On the ' racial ' structure of North Sea autumn-spawning herring. *J. Cons. perm. int. Explor. Mer.* **33,** 67–80.