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AN INTRODUCTION TO A STUDY OF THE MARINE ECOSYSTEM AND THE LOCAL HERRING STOCK IN LINDÅSPOLLENE

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ABSTRACT

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A study of the marine ecosystem in a landlocked fjord (Lindåspollene) with a self-contained herring stock has been initiated. On the basis of preliminary investigation a brief description of topography, hydrography and general biological features of the Lindåspollene is given. The plans for the projected long term research are described and discussed.

INTRODUCTION

At the 1961 symposium on «Herring population studies», arranged by the International council for the exploration of the sea, (ICES), the following recommendation was adopted (ANON. 1969):

> «In view of the size and great complexity of the biological, ecological and other processes governing the population dynamics of the herring stocks, and of the extent and complexity of scientific problems involved in understanding them, the Symposium recognizes the need for setting up intensive and comprehensive studies on a small, self-contained, easily accessible herring population. It further recognizes that such populations are known to exist in at least one member country. It therefore recommends that the Herring Committee of ICES should explore the possibilities of such investigations being initiated».

As a result of this recommendation a special working group was set up to study various localities, particularly within the Norwegian fjord systems which might meet the requirements for these studies.

The working group studied three localities near Bergen: Heiamarkpollen 36 km south of Bergen, Fjellspollen 18 km southwest of Bergen and Lindåspollene 36 km north of Bergen (ANON. 1969). The only really self-contained stock was found in Lindåspollene, but the working group agreed that the herring in Fjellspollen was of greater interest as it contained both spring and autumn spawning populations.

For various reasons the ICES did not find it possible to embark on the proposed research programme, but recommended that national laboratories started such investigations either individually or on a bilateral basis.

The Institute of Marine Research, Directorate of Fisheries, decided to follow up the Council's recommendations on a national basis. Lindåspollene were selected for the study because the herring stock there is largely self-contained and only slightly influenced by herring stocks in the surrounding fjord sytsem (ANON. 1969). As important parameters of the herring population are intimately related to chemical, physical and biological conditions in the environment, it was felt that a comprehensive study of the entire ecosystem would be desireable. In order to undertake such a study it was necessary to engage other marine laboratories, and in 1970 a cooperative research programme for the study of herring and its environment in Lindåspollene was initiated with the Biological station, Espegrend, University of Bergen.

In 1971 a large industrial complex was planned at Mongstad, which is located about 15 km north of Lindåspollene. In connection with this development a housing project for about 200 persons is under construction near Lindås (Fig. 1), and for a period of four years sewage from these houses will be discharged into Lindåspollene. As further urbanization of the area must be expected, a study of the effect of sewage pollution on the dynamics of the ecosystem will be one of the important aspects of the investigation.

The purpose of the present paper is to give a preliminary description of the environmental and biological features of the Lindåspollene ecosystem, and to present the objectives and long term plans for the investigations.

GENERAL DESCRIPTION OF LINDÅSPOLLENE

TOPOGRAPHY

Lindåspollene consist of three major basins separated by shallow sills (Fig. 1). The outermost basin, Straumsosen, with adjacent inlets has a surface area of 2.205×10^6 m^2, and it has access to the Lurefjord through three narrow channels. The maximum depth in Straumsosen is about 60 m, and the sill depth between Straumsosen and the middle basin, Spjeldnesosen, is 5—10 m. Spjeldnesosen is the deepest and largest of the basins with a surface area of 3.782×10^6 m^2 and a maximum

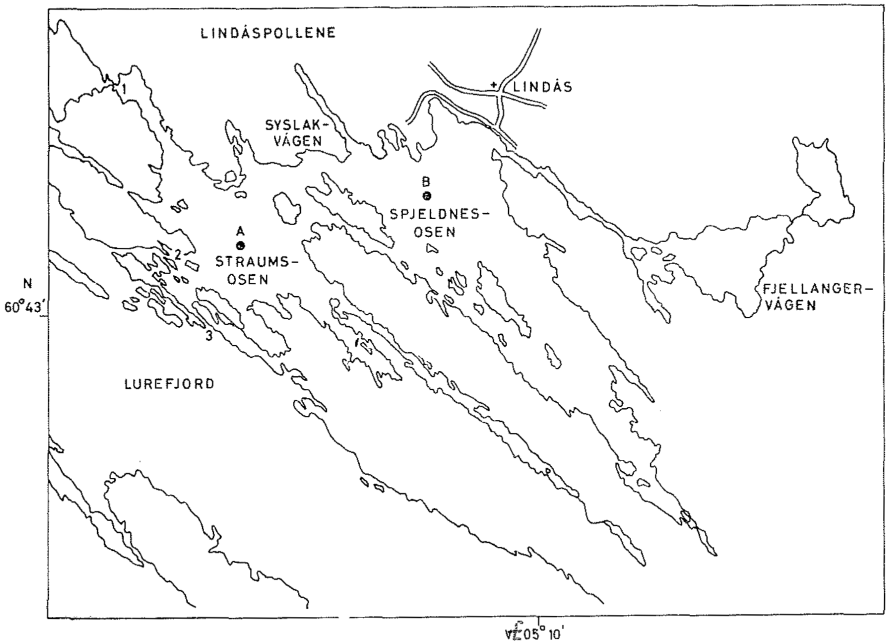

Fig. 1. Lindåspollene. A and B) Hydrographical stations, 1, 2 and 3) outlets to Lurefjord.

depth of about 90 m. A narrow channel about 2 km long leads into Fjellangervågen, the smallest of the three basins, with a surface area of 0.885×10^6 m^2 and a maximum depth of about 80 m.

The shores around Lindåspollene are generally rocky and steep, but at the heads of the inlets there are beaches with bottom types ranging from gravel to soft mud. The sediments of the bottom deeper than about 25 m in the major parts of Fjellangervågen and Spjeldnesosen consist of a very soft, black ooze whereas in Straumsosen they consist of a mixture of mud, sand, gravel and shell-fragments.

The landscape surrounding Straumsosen is rocky and barren which is characteristic of the outer West-Norwegian coastline. Fjellangervågen and the southern half of Spjeldnesosen are surrounded by farmland and pine forest. In general the area is sparsely populated, and there is very little industry. The district of Lindås (Fig. 1) has a population of about 300, and about the same number of people inhabit the farms in the surrounding area.

HYDROGRAPHY

The tidal range measured on 8—9 December 1970 was 35 cm, but according to local residents the average range is about 50 cm. With a total surface area of 6.872×10^6 m^2 and a total volume of $153.313 \times$

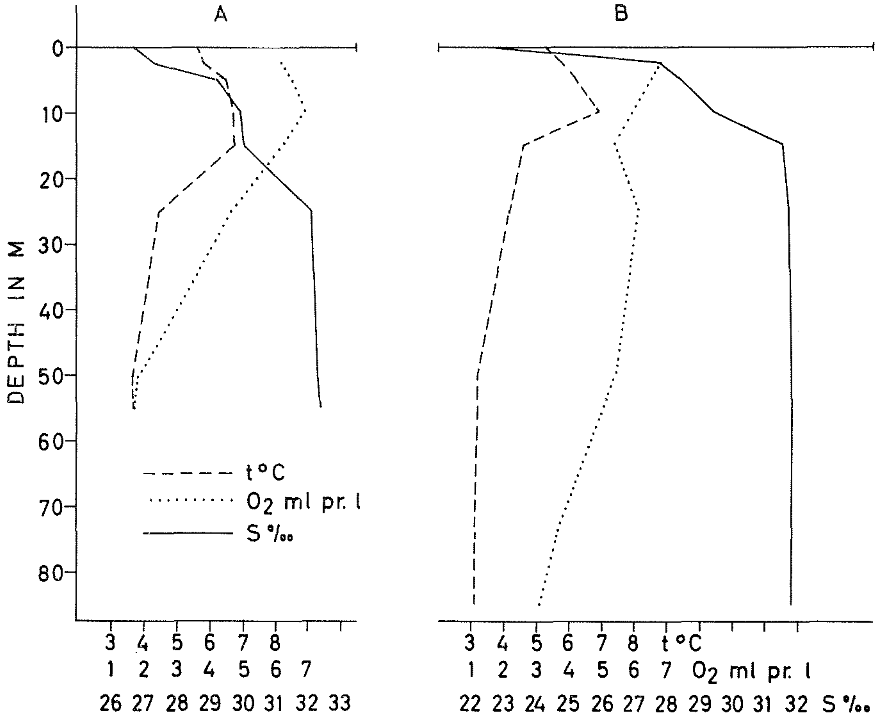

Fig. 2. Vertical distribution of temperature, salinity and oxygen at station A in Straumsosen and station B in Spjeldnesosen, 8 December 1970.

10^6 m^3 the exchange of water during a tidal cycle would be about 3.436×10^6 m^3 or about 2% of the total volume.

Fjellangervågen, the southern half of Spjeldnesosen and the inlets adjacent to Straumsosen are as a rule covered by ice about 2—3 months each winter.

A small lock used to be in operation in one of the entrances to Lindåspollene (2 in Fig. 1), but because of a decline in shipping in the area the lock gates have been permanently open since 1964. According to local residents this has had a marked effect on the water masses in Lindåspollene as evidenced by a distinct reduction in ice cover. An additional effect may be increased immigration and emigration of fish.

Preliminary investigations carried out during 1964 showed that Fjellangervågen differed from the rest of Lindåspollene in having hydrogen sulphide in the water at depths in excess of about 25 m. Partly for this reason and partly because of the long ice cover in the area, Fjelllangervågen will not be studied during the first part of the investigations in Lindåspollene.

Fig. 2 shows the vertical distribution of three hydrographic parameters in the centre of Straumsosen (A) and Spjeldnesosen (B) on 8 December 1970. The watermasses below 25 m in Straumsosen and below 15 m in Spjeldnesosen were rather homogeneous in salinity and temperature, whereas the oxygen values showed a sharp decline with depth in Straumsosen. The surface salinity was considerably lower in Spjeldnesosen than in Straumsosen, and in the deeper layers the salinity at the former station was about $0.5^0/_{00}$ lower than at corresponding depths in Straumsosen. The temperatures of the watermasses deeper than about 25 m ranged from 3.1 to 4.5°C, which is 2—3°C lower than the bottom temperatures of West-Norwegian fjords (AASEN 1952, SÆLEN 1962).

GENERAL BIOLOGICAL FEATURES IN LINDÅSPOLLENE

The benthic macrovegetation in the area is sparse and largely limited to Straumsosen and the northern part of Spjeldnesosen. Large parts of the shore are too steep for macrovegetation to be successful, but where it is a convenient slope there is some growth of *Ascophyllum nodosum, Fucus vesiculosus* and *F. serratus.* At depths of 5—8 m dense concentrations of calcareous algae, (*Lithothamnium fornicatum*), have been observed, and at depths of 1—3 m some *Laminaria saccarina* also occurs (SVENDSEN, verbal information). On bottoms of sandy mud at the head of the inlets are small concentrations of eel-grass (*Zostera marina*).

The zooplankton studied during December 1970 revealed a very low species diversity, but an extreme dominance of *Pseudocalanus elongatus* in the uppermost 50 m. In the deeper layers of Spjeldnesosen the zooplankton was dominated by copepodite stage V of *Calanus finmarchicus.* Other abundant forms were *Oithona* spp., *Oncaea* spp., and small chaetognaths. The zooplankton biomass measured as displacement volume was about 0.1 ml/m³ in the 0—25 m layer, about 0.2 ml/m³ in the 25—50 m layer, and in the deepest parts of Spjeldnesosen (50—85 m) it was about 1.0 ml/m³.

Qualitative samples of the benthos collected by an epibenthic dredge with a net of 0.5 mm mesh size revealed significant differances between the two basins. In Spjeldnesosen the net was full of a black, evil smelling ooze, and no animals were found after sieving with 1.0 mm mesh size. In Straumsosen the dredge contained a mixture of mud and sand with only a faint smell of hydrogen sulphide. The fauna was dominated by the cumacean *Diastylis rathkei,* the polychaetes *Chone duneri,* species of the family Aphroditidae and the brittle-stars *Ophiura albida, O. affinis,* and *O. sarsi.* A few specimens of the cumacean *Leucon nasicus* and the mysid *Mysis mixta* also occurred in the samples. The latter species has not previously been recorded south of Trondheimsfjorden.

Observations made by SCUBA-divers supported the impression of a low species diversity in the area (SAMUELSEN and HØISÆTER, verbal information). The muddy bottoms deeper than about 30 m in Spjeldnesosen were dominated by the polychaete *Chone duneri,* and the rocky bottoms at depths between 20 and 30 m by sedentary polychaetes, particularly *Placotegus tridentatus.* In the latter zone large individuals of the Iceland scallop, *Chlamys islandica* were observed.

In Straumsosen the fauna appeared more diverse, but largely the same species dominated as in similar habitats in Spjeldnesosen. *Chlamys islandica,* however, did not occur in Straumsosen. The tunicate *Ciona intestinalis* was very abundant at depths from 3 to 15 m and completely dominated the benthos on hard bottoms. This species was also observed along the rocky shores of Spjeldnesosen.

In Straumsosen an individual of the mysid *Heteromysis formosa* was found. Only one specimen of this species has previously been recorded in Norwegian waters (BRATTEGARD, verbal information).

Oysters (*Ostrea edulis*) were previously grown commercially in inlets adjacent to Straumsosen, but the oyster industry tapered off during the years following World War II and is presently nonexistent (SOLHEIM, verbal information).

Herring has been caught commercially in Lindåspollene for centuries and sold locally or on the Bergen fish market. Gill nets were the traditional gear, but beach seines and in recent years purse seines have also been used. Estimates of the fishing effort and annual catch are only available for recent years. Gill nets are used by local inhabitants particularly during the spawning season, and during August—September a few small purse seiners using artificial light have operated in the area. The estimated gill net catch is less than five tons per year, and the purse seine fishery yielded about 15 tons. Assuming 20 tons as the maximum sustainable yield and five years as the turn-over time (Fig. 3), the minimum standing stock would be about 100 tons. This stock size would satisfy the requirements defined by the ICES working group (ANON. 1969).

Investigations of herring samples taken during 1963—64 showed that the population was a spring spawning one, differing from the oceanic stocks in racial characters such as vertebral counts and growth rate. The mean length of the herring at the end of the fourth year of life was 24.5 cm. A similar slow growth of herring has been found in other landlocked fjords such as Lusterfjorden (AASEN 1952).

Bimodality in the length distribution (Fig. 3) indicated a small degree of mixing with other stocks (ANON. 1964). The two components in the samples were easily distinguished by growth rate and vertebral counts. The component with relatively slow growth and a low vertebral

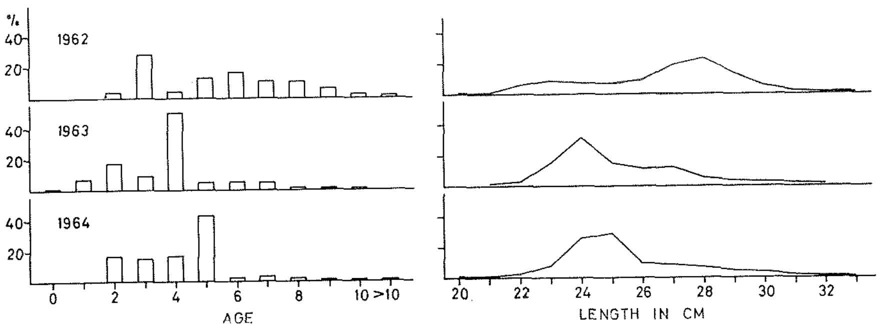

Fig. 3. Age and length distribution of herring from gill net catches in Lindåspollene during 1962—64.

count was overwhelmingly dominant during 1962—64. This group consisted of herring up to 14 years old, but the 1959 year-class was the most abundant. Tagging experiments carried out in November 1962 have shown that some herring migrate out of Lindåspollene, but it is not clear to which component of the population the recaptured fish belonged.

According to information received from the local people, the herring spawn particularly in a small area of Syslakvågen at depths from 0—5 m. In some years scattered spawning has also occurred in other areas near Syslakvågen.

The period of spawning is in the second half of March. The maturity stage distribution in samples collected during 1962—64 confirm that March is the main spawning period, but occasional individuals in spawning condition were recorded until early May.

In autumn the purse seiners also catch sprat (*Clupea sprattus*) together with herring in Straumsosen. There are no reports of spawning sprat from Lindåspollene, and they are most likely immigrants from the outside fjord system.

Other fish species such as mackerel (*Scomber scombrus*), cod (*Gadus morhua*) and pollock (*Pollachius pollachius*) are caught by local fishermen, but none of these species is sufficiently abundant to be of any commercial value.

Species of Cottidae, Labridae and Gobiidae occur along the shores everywhere in Lindåspollene. The Gobiidae particularly are sufficiently abundant to play a significant role in the energy budget of the ecosystem.

PROJECTED LONG TERM RESEARCH

THE ECOSYSTEM

The ultimate aim of the ecosystem studies in Lindåspollene is to build a dynamic mathematical model of the energy flow through and the cycling of matter in the ecosystem. By model simulation and optimization (WATT 1968) it is hoped to gain sufficient insight into the intricacies of the biological situation to be able to manipulate the system for the benefit of man. Optimal management of the system would involve attempts to increase the yield of the herring fishery, to cultivate marine molluscs and crustaceans and to guarantee continued recreational use of the area.

As no information is available at present about either the biotic or the abiotic properties of the ecosystem, it is felt that it is premature to think in terms of a model at an advanced level of sophistication. Rather, the immediate aim is to gather pertinent information on which to build a crude box model of energy transfer in accordance with the concept of trophic levels (LINDEMAN 1942). The box model will be the basis for further modelling of the entire ecosystem or sub-sets thereof.

In order to understand the observed temporal and spatial variability in biological properties one must be able to monitor the important hydrographic parameters, i.e. the vertical and horizontal movement of the water masses, and the heat and salt budgets. Eventually, attempts will be made to build a mathematical model for the water circulation in Lindåspollene.

The projected immediate (a) and long term (b) research of the Lindåspollene ecosystem is summarized below.

Hydrography

a) Annual cycles in major parameters such as temperature, salinity, density and oxygen in the water column in Straumsosen and Spjeldnesosen.

b) Horizontal and vertical movements of the water masses, the salt budget, the heat budget, mathematical modelling of circulation.

Botany

a) Primary production and standing crop of phytoplankton and benthic diatoms, standing crop of macrovegetation.

b) Modelling of primary production in relation to environmental parameters such as light, nutrients and physical properties of the water masses.

Zooplankton

a) Quantitative composition, diversity, seasonal fluctuations, trophic groupings, standing crop.

b) Energy flow through populations of dominant species, modelling the «interrelationships» between phytoplankton and zooplankton.

Zoobenthos

a) Distribution and species composition of benthic communities, standing crop, trophic groupings.

b) Energy flow through populations of dominant species in the infauna and epifauna, quantitative studies of meiofauna, total oxygen comsumption by the sea bed.

Fishes (other than herring)

a) Energy flow through populations of gobiid fishes, particularly *Gobius flavescens*.

Microbiology

a) Rate of decomposition of organic matter and regeneration of nutrients in the water masses and in the sediments.

Systems analysis

a) Introductory box models of energy transfer, efficiencies between trophic levels.

b) Dynamic modelling, simulation experiments.

The research listed as a) above is presently under way or near completion except for the microbiological aspects. The most efficient way of carrying out large scale ecosystem analyses would be to engage experts in the various disciplines. As neither the funding nor the qualified manpower available permit this, the policy is to engage graduate students in oceanography, fisheries and marine biology in addition to permanent research staff at the Institute of marine research and the Biological station, Espegrend. Projects for the students have been selected with the aim of providing pertinent data for the initial modelling. This approach has the added advantage of training students in team efforts and integrated research.

THE HERRING INVESTIGATIONS

The vertical and horizontal distribution of the herring will be investigated by echo surveying. This programme will be performed by monthly or fortnightly surveys along permanent transects in the area. Particular studies of stock assessment using acoustic methods will be made at selected times of the year when the herring distribution is most suitable for such studies.

Sampling with gill nets of various mesh sizes will be performed monthly, and the material will be analysed in order to monitor the maturation cycle of the stock and to estimate individual growth.

Mesh selection in gill net catches prevents true estimates of the age composition of the stock and therefore some purse seining will be done in summer or autumn. Commercial fishing has shown that during this season the herring is particularly susceptible to purse seining, especially if combined with the use of artificial light.

As the herring in Lindåspollene spawns in shallow water in well defined areas, the stock is particularly suited for studies of spawning behaviour and estimation of the spawning stock. Attempts will be made to estimate the spawning intensity by mapping the spawning area and counting the abundance of eggs per unit area. Variation in spawning time from year to year in relation to chemical and physical properties of the environment will be studied. Hatching time can be estimated by frequent larval surveys on the spawning grounds, and the dispersal and survival of larvae will be investigated in the period following hatching. In this connection it is of particular interest to test the efficiency of various types of sampling gear.

Estimates of the rates of survival of the herring in Lindåspollene can probably only be obtained from tagging experiments. Tagging with Lea's external tags in 1962 resulted in extremely high numbers of returns because the externally tagged fish were highly vulnerable to gill nets. On the other hand, returns from internally tagged fish will be severely underestimated because the herring is used exclusively for human consumption, and such tags are only occasionally observed when the fish are gutted. Recent developments in tagging techniques (GUNDERSEN 1960) combine the advantages of external and internal tagging, and these methods may be suitable for tagging experiments in Lindåspollene. As no regular commercial fishing takes place in the area, the tagging operations will have to be followed up by an extensive fishing effort.

When the various parameters of the herring population have been estimated with reasonable confidence intervals, an attempt will be made to build computer models of the population dynamics which may be amenable to simulation experiments aimed at suggesting refinements of the model.

The herring stock in Lindåspollene is well suited for short term biological and experimental studies as recommended by the ICES Working Group (ANON. 1969). Such studies include behavioural studies, genetical studies, experiments with tagging techniques, and experiments with sonar equipment for estimating fish abundance, target strength etc.

THE POLLUTION STUDIES

A research programme has been started to measure the possible effect of the sewage discharge into Lindåspollene on the production of phytoplankton and on the steady state conditions generally. Primary production measurements by ^{14}C-technique, chlorophyll estimates, and estimates of total organic matter in the water masses will be carried out throughout the year, and physical and chemical parameters such as light, temperatures, salinity, oxygen, nitrates, nitrites, ammonium, silicate, phosphate, and pH will be measured simultaneously.

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