OBSERVATORY TECHNOLOGY IN FISH RESOURCES MONITORING

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Abstract: Marine resources are often monitored by means of standardized survey giving a snapshot picture of the state of the stocks. Comparisons of temporal variation in such snapshot pictures are used to evaluate present state and predict future development. To secure comparability and avoid variability such surveys are strictly standardized and keep away from periods and areas of high dynamics. However, the interesting processes and the most informative areas and periods to study is exactly the dynamic ones where the function and performance of the ecosystem is most apparent. We call such areas for “Ocean hubs” and we will in this paper describe an acoustic system using the observatory approach to monitor and extract detailed biological information as well as physical-biological couplings of important to ecosystem function. The system is mounted in a Norwegian fjord opening and designed to monitor flux of herring to and fro the overwintering area. Two 38 kHz scientific echo sounder are mounted on the sea floor looking vertically to the surface and quantify fish density. An 18 kHz sonar insonifies a cross section of the fjord opening including the volume covered by the sounders and is used to evaluate how representative the sounder volume is. An upward looking Acoustic Doppler Current Profiler observes the same layers of herring as the echo sounders and is used to measure the relative speed of the fish compared to water. The system is cabled to land and data can be observed from the office settings adjusted according to needs. Some of the information is posted on the Internet. The results are promising showing that new knowledge and understanding about fish behaviour, migration speed, diurnal dynamics etc. can be obtained though observatory techniques.

Keywords: Acoustic observatory, biomass flux, ecosystem understanding, fish behaviour
1. INTRODUCTION
Assessment and management of marine resources are normally based combinations of fisheries dependent and fisheries independent data. Most commonly, fisheries independent monitoring of exploited marine stocks is based on various kinds of scientific surveys. Typically, such data are integrated with fisheries based information to a system for annual stock evaluation and management advise. The new focus on ecosystem approach in management of marine resources demands detailed information on the dynamics and interaction among fish species and fish-plankton interactions. Scientific surveys to day are focused on assessing abundance estimates comparable to estimates from previous surveys. This requires that observations be taken when dynamics are at minimum to avoid corruption of the snapshot picture established by these surveys. Such surveys are thus not optimal for quantifying species interaction and physical-biological interaction under an ecosystem perspective.

Application of observatory technology with continuous recordings over time gives a true representation of the temporal dynamics in density and vertical distribution. The approach is a complementary to snapshot surveying and may be particularly useful in areas of high dynamics. Such technology is being developed for physical oceanography and plankton recording but no development for quantitative resource monitoring is to our knowledge developed. Utilisation of this technology might become important for collecting information on species interaction, and migration and behavioural biases on survey efficiency. The approach may thus improve standard survey techniques in taking the ecosystem approach.

Norwegian Spring Spawning Herring (NSSH) has been overwintering in the Ofoten and Tysfjord areas since rebuilding in the 1980s after fisheries induced collapse (see e.g. Figure 1). During this period of about three months extreme densities of herring passes the fjord openings during immigration and emigration. This generates a special case for direct observation of behavioural dynamics of a commercially important fish stock.

It is the goal of paper of this paper to describe an acoustic observatory in the Ofotfjord and exemplify the potential of this new monitoring approach by data collected during the wintering periods of 2002 to 2004. Some aspect of future application is discussed.

2. TECHNOLOGY IN THE OFOTEN OBSERVATORY
In November 2003 we established an acoustic observatory at the entrance of the Ofotfjord (Figure 1) composed of echo sounders, sonar, and Acoustic Doppler Current Profiler (ADCP). The fjord has been an important overwintering area for herring during the last two decades. Herring are also distributed in the nearby Tysfjord and to some extent in the Vestfjord (Figure 1).

2.1. Echo sounders
In abundance surveys vertical echo sounders are used to sample marine life along the ship’s cruise track with the aim of establishing a representative picture of the biomass in the survey area. In our case we used two EK60 38 kHz echo sounders mounted on bottom at 400 m and 500 m depth in the northern part of the fjord (Figure 2). This is the same type of echo sounder system as used during standard acoustic surveys for herring and other commercial species. The transducers had a manipulated beam with a 30° x 8° opening with the wide angle transverse to the fjord direction to maximise the observation volume in the herring migration.
direction. System calibration was secured through the use of a ROV to move the calibration sphere through the beams.

Figure 1. Distribution of herring during overwintering and the location of the instrumentation (red line).

Figure 2. Schematic presentation of the instrumentation. Only two vertical sounders (not four) were used. An AUV was used in the project but is not presented here.

Distances from shore were 1000 and 1400 m. The pressure vessel contained the electronics and the transducers were mounted in gimbals to secure an perpendicular view independent of the bottom slope. The instrumentation was connected to an instrument cabin on shore through a combined electricity and Ethernet cable. The sounders were powered by 220 V DC and the data were logged on a PC.

The echo sounder operated at 1000 w, pulse repetition frequency varied between 0.5 to 5 seconds, pulse length of 1 ms and sound frequency at 38 kHz.

Main task: Use the two echo sounders to monitor changes in density by depth and time during herring immigration, hibernation and emigration. Observe migration speeds when recordings
are resolved in single fish target. Monitor behavioural characteristics of herring during the overwintering situation. Use the echo sounder results as representative for the fjord opening. Main obstacles: The sampling volumes of the sounders are small and the transducers are located only on the northern side of the entrance of the fjord.

2.2. Sonar
Our hypothesis that the echo sounders record a representative picture of the biomass in the vertical section through the fjord opening needs validation. Side looking sonars have the potential for fish detection to horizontal ranges of order several kilometres, even in shallow waters, providing spatial coverage significantly greater than that achieved with conventional echo-sounders. Also, due to the directional differences they are complementary as monitoring tools. In our case a side looking sonar was set up to sonify a horizontal channel through the echo sounder observation volumes.

Farmer et al. successfully developed and used a 12 kHz sidescan sonar system to track sockeye salmon to a range of 7km with up to 25 dB signal-to-reverberation ratio. This system has also been used in stationary mode to track herring schools to a range of 1.2km in shallow waters off the coast of Denmark. This system was also used in the Often fjord (Figure 2). The basic acoustic system consists of a 40-element ($20\lambda$), 12 kHz sidescan array connected to a EDO model 248 Sonar Transceiver. The sonar transceiver is capable of delivering up to 2.0 kW (electrical) power to the array. The 12 kHz operating frequency was selected as a compromise between low acoustic absorption while maintaining modest transducer directivity. The sidescan array has a total length of 2.49 m, yielding a horizontal beam width of 2.8° (to -3dB). The sonar is made up of model TR-229 Tonpilz piston elements assembled in a linear array and calibrated by EDO/Western. In the vertical plane, the array elements have a beam width of 122° and a front-to-back ratio of -6dB. To improve this ratio we used a 30 cm diameter cowling behind the array lined with 12 mm thick cork loaded rubber acoustic absorbing material as backing material, which provided improved forward directivity.

Main task: The objective of this part of the project is to determine whether it is possible to use the combination of horizontal and vertical sonars to monitor densities fish immigration to and emigrating from a fjord. We want to demonstrate the feasibility of the combined use of an intermediate range, 12 kHz, fisheries sonar (IRFS) and vertically mounted 38kHz sounders (EK60) and identifies some of the practical applications and constraints on its use.

Main obstacles: Horizontal looking sonars are susceptible to temperature stratification creating sound channel that prevents the system from observing the volume of interest.

2.3. Acoustic Doppler Current Profilers (ADCP)
Traditionally ADCPs are used for measuring water current and vessel speed by measuring the Doppler shift from the sea bottom or particles in the water. Fish and other marine life are regarded as noise that biases the estimates. Such bias correlated with a diurnal rhythm is reported and associated with species of micronekton in dense sound scattering layers swimming coherently at sunrise. Also a strong diurnal signal from the ADCP after a cold-water intrusion from the shelf slope region south of the Bungo Channel has been seen. They explain this by an immigration of zooplankton from outside the bay. Zedel et al. used a moored downward looking ADCP to observe movements of schooling herring in Ofoten. They observe horizontal and vertical movement of the fish schools with highest speeds during daylight.
A Nortek Continental ADCP operating on a frequency of 190 kHz and was placed 804 m North East of the two EK60 and 608 m from land. Due to the high frequency the operation range is limited to about 150 m. The instrument was located at this depth with transducer looking upward as shown in Figure 2. Nortek introduced the 190 kHz Continental ADCP based on the ‘Paradopp’ hardware platform, but with a redesigned receiver and transmitter. The single-disk ceramics are large (about 150 mm in diameter) and the mechanical design is based on a combination of plastic housing elements and titanium cups. The current profiler can be operated in stand-alone mode with internal recorder or in real-time mode using cables or GSM/radio/acoustic modems.

Main task: With the CP we will measure speeds within and outside the herring schools and thereby evaluate fish migration. When densities and distribution are available from the echo sounders and the sonar the migration speed from the CP can be used to quantify flux of biomass.

Main obstacles: The limited depth window that could be observed create uncertainty of the migration speed estimates as much of the biomass is found below 150 m.

2.4. Land facilities and communication

A small instrument container hosts the computers and data storage capacity. Cables connects the sounders and sonar to the computers on land while the data from the ADCP was store at sea for later download. A radio connection for transfer of last observations existed periodically. A mobile phone give access to the instrument computers and the data can be inspected and instrument settings adjusted according to needs. Later, we have established a broadband radio link between the instrument container and a broadband connection point on main land. Thus, part of the data can now be streamed to the Internet or downloaded for analysis.

![Figure 3. Comparison of area backscattering from the two near by echo sounders. See especially the day maximum from the outer transducer compared to the innermost.](image_url)

3. RESULTS AND APPLICATION

The observatory has been in use since November 2002 and still the echo sounders collect data. The side looking sonar and the ADCP operated only during the winter 2002-2003. A tremendous amount of data has been collected associated with behavioural dynamics, stock
assessment, and ecology (species interaction). In this section we will emphasis on some examples to illustrate the potential of this new approach to ecosystem monitoring.

3.1. Understanding and quantification of behavioural dynamics
Behavioural dynamics is of great importance for the function of ecosystems and may seriously affect the reliability of scientific surveys. Behaviour over time is difficult to observer because presence over seasons normally is not feasible and because the most common observation platforms affect the natural behaviour. With this technology we have got detailed data both with respect to temporal and geographic resolution. We found e.g that the diurnal dynamics between the two near by echo sounder reflected processes that would be difficult to detect from a vessel (Figure 3, Patel and Godø in prep).

The horizontal sonar should ideally give a qualitative picture of the distribution of biomass of herring over the cross section of the fjord. Unfortunately, the stratification of the water masses created sound channels at surface that confused the interpretation of the sonar results. Echograms over several days demonstrate higher sonar backscattering at night (upper panel Figure 4) when herring move to the surface as shown in the echograms of the echo sounders (Figure 4 lower panel).

3.2. Assessing the fjord stock by estimating biomass flux

Estimation Biomass flux through the vertical section monitored by the observatory depends on:
- Density estimation over the EK60 transducers
- Extrapolation of densities from the two EK60s to the whole fjord section
- Estimation of migration direction and speed of the herring.

In our case the horizontal looking sonar observed only fraction of the water column, probably the surface part, due to the sound channel created by the hydrographical situation (see 3.1). Thus the basic assumption behind the concept is not truly valid in our case. For demonstration purposes we have in the following exercise assumed that the average density over the EK60s is representative for the whole fjord section. The biomass over the transducers is estimated based on an average herring size of 30 cm, a weight length relationship of $W=(4.95e-3)*L^{3.131}$ and a TS-length relationship of $TS=20\log(L)-71.9$. Figure 5 shows the trends in total herring density during various periods in the 2002-2003 season.

![Figure 4. Echogram showing the diurnal migration. a) Horizontal looking sonar. b) Vertical looking echo sounder. Time ticks is in 10 minutes intervals.](image-url)
The biomass flux (kg/s) is given as:

$$F = \rho \cdot v \cdot \cos \theta \cdot S$$  \hspace{1cm} (1)

where $\rho$ is the density (kg/m³), $v$ is the mass speed (m/s), $\theta$ is the angle to the normal vector of the plane, and $S$ is the area (m²) of vertical section through the fjord opening where instrumentation is located.

The biomass density is calculated from the two bottom mounted transducers. The mean depths of the transducers are 501.4 m and 402.0 m. The average biomass during the period of ADCP operation for the two transducers is 47 kg and 75 kg per m². The average volume density is thus given by $\rho = (47 \text{ kg} / 501.4 \text{ m}^3 + 75 \text{ kg} / 402 \text{ m}^3) / 2 = 0.140 \text{ kg/m}^3$. The migration speed ($v$) of the biomass as observed from the ADCP (Patel and Godø in prep.) during the period December 2-28 2002 is $v = 4.4 \text{ cm/s}$. The angle between the speed vector and the cross section of the fjord ($\theta$) is 90 degrees and thus $\theta = 0$. The cross section ($S$) of the fjord was calculated from data from EM300 and EM 1002 bottom mapping echo sounders and gives $S = 1243500 \text{ m}^2$. Biomass flux ($F$) based on the above calculations gives $F = 0.140 \cdot 0.044 \cdot \cos (0) \cdot 1243500 = 7669.3 \text{ kg/s}$. A crude estimate of biomass flux through the fjord section in the period 02/12/18-02/12/28 is thus 7.7 tonnes/s. In this case it translates to a total influx to the fjord in this period of 227000 tonnes, which seems realistic taken into account that the total biomass in the fjord amount to several million tonnes. Accurate estimates of biomass flux will be further explored through studies of speed of single targets through the split beam echo sounders. Also, an ADCP covering the whole water column would improve the data as the different layers of herring may move at different speeds and direction.

3.3. Species interaction

Stationary acoustic monitoring gives a unique opportunity for studying species interaction. In our case we can demonstrate orcha diving activities in the are with very high food density. This might over time give valuable information about the feeding behaviour and activity.
patterns of these important predators. Also, at top and bottom of the herring layers we can identify larger fish (from their acoustic target strength) and their activity during the diurnal migration of herring. These features and their potential as a means of quantifying predator–prey interaction still need further analysis.

4. FUTURE PERSPECTIVES

To our knowledge this is the first time observatory technology has been used to monitor and quantify biomass and behaviour of commercially exploited marine resources. The results so far are very promising and raise a number of new issues of importance to stock assessment and ecosystem approach to modelling and management. We think that the approach has a large potential related to improving understanding and quantification of processes of utmost interest in modelling, e.g. migration speeds, species interaction, fish availability to surveys etc. There are a lot of potential improvements in the technology that will give more flexibility to utilisation and enhance efficiency:

- Better integration of instrumentation, e.g. sounders and ADCP
- Capability to manoeuvre the sounder/sonar transducer to track schools or single fish or events of species interaction remotely from the operator’s office.
- Minimize power consumption so that automatic systems can be launched for long-term operation in oceanic locations.
- Automatic systems that can scan a fjord entrances and inform on important events, e.g. emigration or immigration of fish.

5. REFERENCES

[10] Zedel, L., Knutsen, T., and Patro, R. Acoustic Doppler Current Profiler Observations of