Hydroacoustic Assessment of Cold-Source Organisms in Hongyanhe NPP Surrounding Waters

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Abstract: Coastal nuclear power plants are facing the threat of plankton invasion. The large-scale outbreak of jellyfish in summer has had aserious impact on the safety of coastal nuclear power cold sources, seriously affecting the safe operation of coastal nuclear power. In addition to continuously strengthening interception and fishing measures, how to effectively detect and evaluate the quantity of marine biological resources such as jellyfish and provide real-time warning of marine biological invasion has become an important topic. This study focuses on early warning of jellyfish invasion and uses a scientific bathymeter (Simrad, Norway, EK60 model, 200kHz) to design and develop an acoustic monitoring system for cold source organisms (jellyfish). The echo integration method is used to measure and evaluate resource density, and real-time monitoring of cold source biological echoes in the sea area near the water intake is carried out to achieve the purpose of marine biological resource disaster warning. After processing acoustic data from July and August 2021 using Echoview software, the density of jellyfish resources was obtained. The monitoring results show that the maximum daily average value of SV is -52.7dB, and the minimum value is -72.3dB. According to the two month experimental monitoring results of the intake of the Hongyanhe Nuclear Power Plant, the system has good monitoring and warning functions and practical application prospects.

Keywords-Jellyfish; Target intensity; Resource assessment

1. Introduction

The cooling water for the circulating cooling water system and other important equipment pieces in coastal NPPs is generally supplied from coastal intakes. The organisms entering the cooling water system from intakes are referred to as cold-source organisms, for which the defense, interception and handling directly influence the safe and stable operation of plants [1]. According to data statistics of INPO, from 2004 to 2008, there were 61 intake blockage incidents in nuclear power plants all over the world, of which nearly 80% incidents led to shutdown of units, and over 20% incidents directly affected the safety system of NPPs. The invasion of external cold-source organisms was the primary cause of intake blockages[2].

For domestic coastal NPPs, cold-source organisms mainly include various jellyfishes, planktons, fishes, shrimps and large algae, etc [3], especially in recent years, the outbreak of jellyfishes in

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coastal regions is serious, and badly threatens the safe operation of coastal NPPs of China. To cope with the outbreak of cold-source organisms, coastal NPPs generally protect their cold-source systems by "net interception + manual lightering and cleaning by fishing boats on the sea", with industrial difficulties of serious weather dependency and impracticability of manual lightering and cleaning by fishing boats during the outbreak of marine organisms [4]. In addition to continuously strengthening protection measures such as interception and fishing, how to effectively pre-detect and evaluate the resources of jellyfishes and other marine organisms and provide real-time early warning of marine organism invasions has become an important topic.

1.1 Application of fishery hydroacoustic method in the assessment of fishery resources

Hydroacoustics is a branch of acoustics [5], and can solve problems related to the detection and information transmission of underwater targets, focusing on the research of the generation, radiation, propagation, reception and measurement of sound wave under water. We use sound wave to detect targets in seawater and transmit information because sound wave attenuates much less than electromagnetic wave and spreads further in seawater. Thus the development of hydroacoustics is very important in the development of marine fishery.

The acoustics assessment of fishery resources is based on object echo value for quantity measurement of resources, and target strength (TS) is critical for converting the integral value of echo to the assessment of resources [6]. Take Norway, a great fishery country in Europe, as an example, hydroacoustic method has been widely used in fishing and monitoring in fishery industry, and proved to be very suitable for investigation and assessment of fishery resources [7], and has become a primary means for the quantity measurement of plankton resources.

As early as 1986, Tatsukawa Ken-ichi et al estimated the number of fishes in Donghu Lake of Wuhan with a shallow lake type fish finder. Based on two way analysis of variance of count values of individual fish finder images changing with time and the density of fishes, it was found that the population density of fishes varies with lake regions. Additionally the total quantity of fishes in Donghu Lake at that time was estimated [8]. From 1991 to 1993, H.J. Lu et al (1995) have conducted acoustic investigation for 229 fish schools in coastal waters to the northeast of Taiwan, and developed an echo signal image processing system for identifying the species of fish schools, which has an accuracy up to 90% in identification of fish species included in the investigated fish schools [9]. Kevin M. Boswell et al (2007) has designed a lightweight transducer platform for horizontal investigation in shallow waters, equipped with instruments including multi-frequency identification sonar DIDSON and BioSonic split-beam fish finder, allowing investigation for waters with a depth of only 1-3.5m[10]. Sarah J.M. Harper et al (2010) has plotted a map of fish school gathering areas by hydroacoustic method to improve the fishery management of Las Vegas Islands [11].

1.2 TS of jellyfishes

TS refers to the dB value of the sound intensity I_r generated by target backscatter relative to incident plane wave sound intensity I_i at 1m from the acoustic center of the target in the direction from the target to active sonar receiving transducer. It is a term describing the back scattering power of incident plane sound wave in sonar equation. Jellyfishes' TS varies with the species and umbrella diameter of jellyfishes and the inclination angle of measurement. TS of jellyfishes is very important because we must convert the obtained acoustic data to the required data of resources [12]. TS of jellyfishes is defined as:

$$TS=10\log\frac{I_r}{I_i}\ (r=1)$$

Where, target strength is expressed by TS (dB); Ii is incident sound intensity (W/m^2); Ir is reflected sound intensity at 1m from acoustic center of target (W/m^2). The acoustic center of target is a virtual point in or near the target. Target strength, known as target reflectance in the past, is an important factor influencing active sonar echo signal strength. Target strength is usually obtained by measurement. A common method involves measurements by a hydrophone placed near an emitter to obtain the average intensity of echo fluctuation envelope and converting it to the sound intensity level at 1m from the sound source according to the two-way propagation loss in the operating sea area. The result minus the sound source level is the target strength.

For this purpose, with jellyfishes at the intake of Hongyanhe NPP in summer as monitoring object, we designed and developed a hydroacoustic monitoring and early warning system based on a split wave beam scientific fish finder to calculate the density and throughput of cold-source organisms such as jellyfishes entering the sea area around interception nets and lay a scientific foundation for early warning of cold-source organisms at the intake.

2. Acoustic monitoring methods

2.1 Monitoring position and sonar

As shown in Fig. 1, there are 5 interception nets at the intake of Hongyanhe NPP. In this study, the sonar monitoring point was set at #3 caisson of the fourth interception net of Phase I intake, using a shore-based monitoring method. The transducer was placed horizontally to sound marine organisms entering the intake. The density of resources was measured and evaluated by echo integration to realize early warning of disaster-causing resources of marine organisms.

The transceiver (GPT) of the scientific fish finder was installed in a distribution cabinet on the caisson platform. The control signals and data of GPT were sent back to an industrial computer in the control room on the shore by a cable to realize remote operation and control of the scientific fish finder.

Fig. 1 Position of Sonar Monitoring System at Intake of Hongyanhe NPP

2.2 Individual target detection method

The acoustic data were processed by Echoview software, individual target identification was conducted for jellyfishes [13], and the number of jellyfish individuals was calculated by counting method. Jellyfish individuals were selected and marked (Fig. 2) with reference to the study of Mutlu et al [14] on the target strength of Aurelia coeruleas and the study of Hirose et al [15] on the target strength of Nemopilema nomurais.

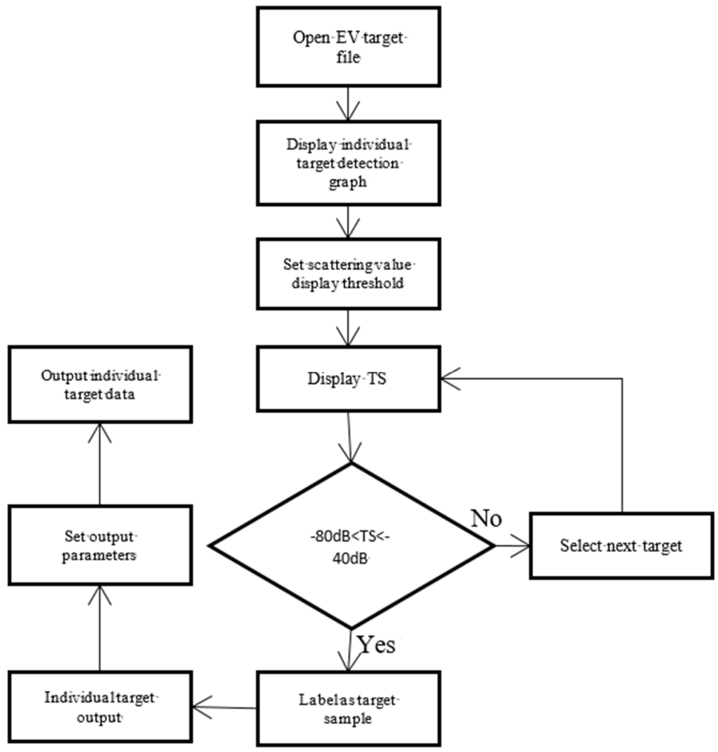

Fig. 2 Individual Target Detection Flow Chart (-80dB is set based on the minimum detection threshold of this study, and -40dB is the intensity range of jellyfish targets)

Create a new EV folder using sonar data processing software Echoview, and add the acquired data file into the EV folder. If the transducer is not perpendicular, the transducer must be set so that it can change the range to depth in the echo sounding map observed by you. Divide acoustic echoes by areas. The acoustic mapping data can be divided into different types by defining areas.

Then conduct individual target detection for the selected area. In Echoview [16], Single Target represents the acoustic echo generated by the individual backscatter target detected by the echometer. Each single target has many features, of which target strength and the distance between single target and transducer are two of the most significant features, other features are also important in the analysis of target strength. The original variable of single target detection can be obtained from the original data. During the analysis of target strength, the minimum target strength must be set with reference to the measured target strength distribution or the known target strength distribution of the studied fish species.

During integration, a threshold must be set to eliminate samples with a target strength value lower than the set value. The integration threshold must be lower than the set minimum target strength threshold by approximately 5dB.

The final analysis result can be output by three methods, i.e. output with areas as analysis unit, output with simple lattice as analysis unit and output with area-simple lattice as analysis unit. Additionally relevant contents such as data value, single target, target length, target strength frequency distribution, straight line and area explanation, etc can be output.

2.3 Development of early-warning model based on sonar monitoring

This system, with a fixed sonar monitoring point set at the intake of Hongyanhe NPP Phase I, dynamically monitors the changes in the volume scattering strength of cold-source organisms entering NPP intake (including unit water body sound scattering strength of cold-source organisms, SV) to develop an early-warning model for cold-source organisms threatening the operation safety of the plant considering the carrying capacity and cleaning capacity of interception nets.

SV is a volume scattering strength (dB) calculated by echo strength of cold-source organisms, i.e. a logarithmic value compared to the reference value. According to studies in the past, SV value of marine organisms is usually in a linear relation with the density or amount of cold-source organisms. Under general sea conditions, $SV<-70dB$ for water body, $SV<-60dB$ for suspended sediment, $-60dB<SV<-40dB$ for planktons such as jellyfishes and Acetes, $-40dB<SV<-30dB$ for fish schools, $SV>-50dB$ for floating garbage (bamboos, woods and foams, etc) in horizontal incident direction, $-40dB<SV<-30dB$ for sea surface and seabed in horizontal incident direction. The early-warning model is developed for three cases, with principles and explanations as follows:

2.3.1 Early warning of transient impact of cold-source organisms

Variance of volume scattering strength of cold-source organisms in unit time ($\Delta SV/\Delta t$), in dB/m3*min, can express the change rate of the quantity of the monitored object. When $10dB < \Delta SV/\Delta t < 20dB$ (10-100 times higher than normal quantity of marine organisms), it means that many organisms are entering the intake, the system will send an early warning to alert the personnel on duty to pay attention to the changes in the quantity of organisms and take defensive measures in advance. When $\Delta SV/\Delta t > 20dB$, it means that a large quantity of organisms are entering the intake, the system will give an alarm.

2.3.2 Early warning of continuous increase of cold-source organisms

Accumulated volume scattering strength of cold-source organisms in a period (ΣSV), in dB/m3.

The accumulated value of four SVs (suspended sediment, jellyfishes, fish schools, floating garbage) in 30min prior to the current time is calculated and compared with the characteristic value of the corresponding type. Then the difference between two SVs of adjacent 30min periods is calculated; the system will give an alarm when the difference is greater than 6 dB (4 times).

2.3.3 Early warning of invasion throughput of cold-source organisms

During cold-source organism monitoring with sonar, when cold-source organisms enter the sonar sounding wave beam, since the acoustic volume backscatter strength (SV) and density (n) of cold-source organisms in group measured by the sonar are proportional to the average individual target strength (TS), i.e. <n>=<SV>/<TS> and since the sonar acoustically radiates the group of cold-source organisms when it passing the wave beam, actually the above equation uses the average of echoes sent and received severally times.

On this basis, the average velocity in this direction from the intake to the shore is measured to calculate the absolute value of the average throughput of cold-source organisms: ｜<F>｜=<n>*<v>

2.4 Sonar monitoring and data processing method

When the installation is completed, the cold-source organisms such as jellyfishes entering the intake are monitored in a real-time manner. The acoustic data are processed by the dedicated software Echoview. After eliminating sea surface bubble echoes produced by waves and wake bubble echoes of passing ships, volume scattering strength integration and individual target detection are carried out.

When acoustic data processing is completed, a secondary check for the analysis result must be conducted. First, check the integrity of data analysis to ensure all data ranges are analyzed except bad data ranges; second, check the accuracy of data analysis, check whether there are areas with an abnormally high or abnormally low density in the evaluation result, and check whether these high-density or low-density areas are consistent with those dense or sparse organism areas on the mapping graphic.

In this study, the integration threshold of SV is set to -34 dB to -70 dB, the echo integration and individual target sounding ranges are within the effective acoustic sounding range (2m - 40m). According to the size of jellyfishes obtained during net cleaning, the min. detection threshold is set to -80 dB, then the daily weighted average of individual target TS is calculated. On this basis, the daily averages of SV and TS are obtained to calculate the daily density of the jellyfishes passing through the sonar wave beam,

(1)<n>=<SV>/<σbs >

Where, SV is volume backscatter coefficient (in m2/m3), and related to SV (in dB) by:

(2)SV=10log SV

σbs is backscatter cross section (in m2), and related to TS (in dB) by:

(3) σbs=10TS/10

3. Result and analysis

3.1 Sonar monitoring result

Fig. 3 shows an acoustic echogram of the actually monitored cold-source organisms entering the sonar wave beam. Influenced by tide height and water depth, the effective monitoring range is 2-40m. The red linear echo at 55m is an echo from the remote seabed; the blue and green echoes at 42m are sidelobe echoes of the sea surface and seabed. It can be seen on the echogram that there is a trend of cold-source organisms getting closer to the sonar wave beam on the surface of the transducer over time, the organisms are characterized by group distribution, giving priority to organisms with an echo strength of -61dB to -49dB. There is a large quantity of organisms showing significant individual features.

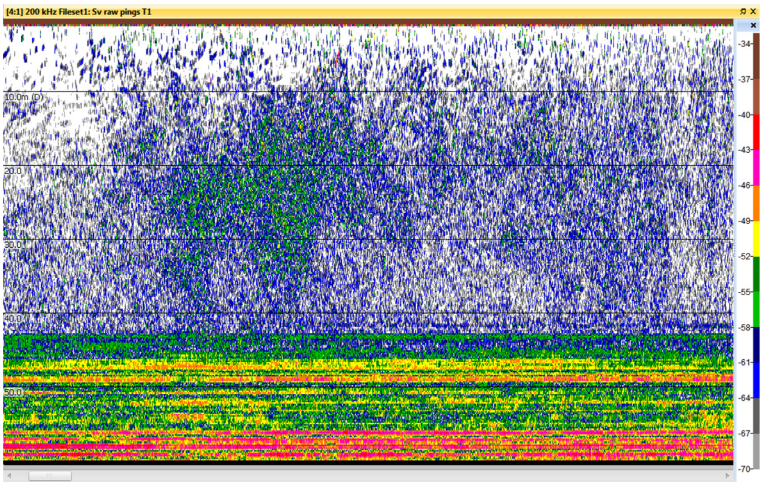

Fig. 3 Acoustic Echogram of Cold-Source Organisms Entering Sonar Wave Beam

3.2 Daily average SV and daily average TS

See Fig. 4 for the statistical results of daily averages of SV and TS monitored in July - August, 2021. The max. daily average SV of Aurelia coeruleas and Nemopilema nomurais, i.e. -62.06 dB, appeared on July 1; the min. daily average SV, i.e. -68.86 dB, appeared on July 20; the max. daily average TS of Aurelia coeruleas and Nemopilema nomurais, i.e. -49.48 dB, appeared on July 9; the min. daily average TS, i.e. -57.1 dB, appeared on July 20.

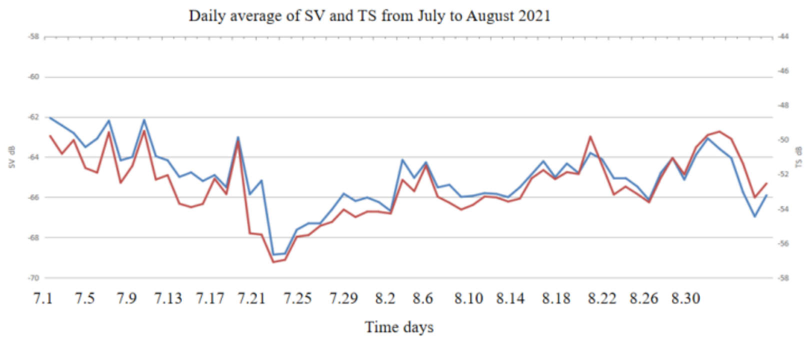

Fig. 4 Comparison of Daily Average SV and TS of Jellyfishes at Hongyanhe NPP Intake in July and August of 2021

3.3 Average density

See Fig. 5 for the statistical results of daily averages of Aurelia coeruleas and Nemopilema nomurais monitored in July - August of 2021. The max. daily average density of Aurelia coeruleas and Nemopilema nomurais, i.e. 0.13 ind./m², appeared on July 19; the min. daily average density, i.e. 0.04 ind./m², appeared on August 28; the daily fishing quantity in open seas was relatively consistent with the tendency of daily monitored density of jellyfishes.

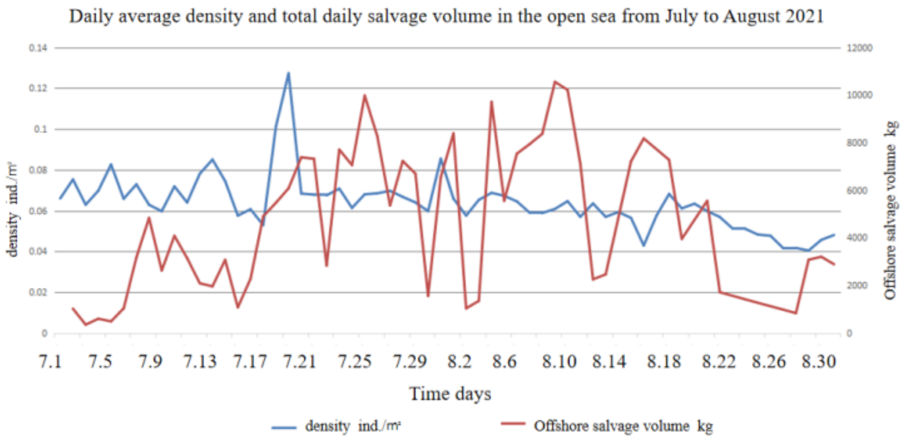

Fig. 5 Comparison of Daily Average Density of Jellyfishes at Hongyanhe NPP Intake and Fishing Quantity in Open Seas in July and August of 2021

4. Conclusions

To cope with cold-source organism outbreak incidents of coastal nuclear power plants, a shore-based sonar monitoring system based on a split wave beam scientific fish finder (EK60) was developed in this paper. This system can effectively evaluate the amount of organism resources entering the sonar range so as to provide an early warning in peak hours of organisms and gain more time to take preventive measures in time. According to the experimental monitoring results obtained at Hongyanhe NPP intake in two months, the system has a good monitoring and early warning function and an actual application prospect, which are discussed as follows:

4.1 Use of horizontal sonar wave beam

Split wave beam scientific fish finder is a professional instrument for acoustic investigation and evaluation of fishery resources[17], with half-power beam angle of 7°. Since the intakes of coastal nuclear power plants are generally designed with a small depth (about 10 m), to increase the acoustic sampling quantity of cold-source organisms, a horizontal wave beam sounding method is used, which has an effective sounding range of over 50 m and an echogram of cold-source organisms that can visually and clearly show the intensity of organisms within the monitoring scope (Fig. 3), to lay a foundation for acoustic monitoring of organisms in horizontal direction and further expanding the acoustic monitoring scope. Due to the horizontal use of wave beams, the echo reverberation at sea surface and seabed cause a certain interference [18], so spatial statistics of average target attitude strength should be considered in a 3D coordinate system. In the future, further study should be conducted in this aspect according to the species of cold-source organisms and changes of flow field at the intake to minimize noise interference and increase the accuracy of resources quantity and provide a strong technical support to decision-making on cold source early warning.

4.2 Evaluation of cold-source organism resources quantity

The NPP cold-source organism acoustic monitoring system in this study is based on individual target sounding and echo integration functions of a split wave beam scientific fish finder, and can monitor the density of cold-source organism resources (Fig. 5). On this basis, the early warning level indication for cold-source organisms is provided. At Hongyanhe NPP intake, the cold-source organisms give priority to jellyfishes in summer. In this monitoring test, it can be seen by comparison between the density of organisms such jellyfishes and the data of fishing at open seas, that there is a tendency of good correlation between them, and the quantity monitoring effect for jellyfishes is good. To obtain more accurate measurement results, a jellyfish species database[19] and the relationship between the average target strength of different jellyfish species and different attitude inclination angle, body length and body weight must be established to evaluate the quantity (wet weight) of cold-source organism resources passing through the intake. Additionally, the acoustic identification of target echo for other cold-source species should be further studied[20].

4.3 Sonar monitoring system

The acoustic monitoring system designed and developed in this study basically meets cold-source organism monitoring requirements of Hongyanhe NPP, but there still some problems requiring improvement, including:

4.3.1 Installation of an additional control system on sonar transducer

The poor sea conditions at Hongyanhe intake in September - November of every year, severe weather conditions and bubbles on the water surface produced by passing ships during net cleaning and fishing operations will greatly influence the sonar echo in the monitoring area. In consideration of these influences, it is planned to install a cradle head and a motor on the support of transducer in the future to realize remote control of attitude angle. When necessary, the angle of transducer can be adjusted to avoid bubbling areas to ensure the stable operation of the system and real-time monitoring of cold-source organisms in the sea area around the intake. Under poor sea conditions, the transducer can be lifted remotely so that the equipment will not be damaged by sea wave (generally the wave is high and sea conditions are severe in the middle of October, when the cold-source organisms are in very small quantities and have less threat on cold source water intaking).

4.3.2 Transducer maintenance

During long-time monitoring in summer, dirty organisms such as algae and barnacles, etc may adhere to the surface of transducer and support. This can affect the accuracy of acoustic monitoring, so divers are sent to check and clean the sonar probe regularly. Besides, when the peak season of every year is over and monitoring work is completed, the sonar support and the complete sonar monitoring system will be taken back and sent to the manufacturer for maintenance so that the system stability and accuracy can be maintained during long-term use.

4.3.3 Dynamic data analysis

The currently developed monitoring system can only provide the real-time SV data of the monitored object, the data of jellyfish density must be processed by professional software, and automatic processing and analysis hasn’t been realized. Therefore, it is necessary to develop a model allowing individual target species identification, size presumption, density and wet weight evaluation for specific cold-source organism species and early-warning level indication to provide an effective guarantee for the coastal nuclear power industry of China.

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