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Fishery Resource Monitoring Methods: A Look at the Present and Future Prospects

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1. Introduction

Recently, we have been hearing a lot about how fishery resources are in crisis. According to the 2018 edition of The State of World Fisheries and Aquaculture (SOFIA) published by the United Nations' Food and Agriculture Organization (FAO), the percentage of ocean fishery resources that are "underexploited or moderately exploited" is falling, accounting for just 7%, while the percentages for "fully exploited" and "overexploited or depleted" are rising to 60% and 33%, respectively. At the same time, human activities, as represented by overfishing, and climate change are presented as factors that can have serious impacts on fluctuations in fishery resources. Of these factors, human activity can be controlled to some extent. In the case of climate change, however, the complex mechanisms involved make it extremely difficult to accurately understand how it affects fishery resources. Moreover, fishery resources are constantly fluctuating, a fact that is a source of uncertainty in itself. It is thought that ensuring the sustainable use of fishery resources will require constant efforts to ascertain or monitor the actual status of fishery resources. Thus, in this paper, I will attempt to contribute to better monitoring methods for fishery resources in the future by reviewing existing methods for monitoring fishery resources and marine organisms and summarizing their characteristics.

2. Current situation for each monitoring method on fishery resources

2-1 Fishery statistics

Fishery statistics mainly provide information concerning catches and fishing efforts (number of fishing vessels, number of operations, or trawling time, etc.) that is obtained from fishing activities. This information is typically arranged by fish species, fishery categories, and regions of the sea. Fishing is a human activity with a long history, and therefore fishery statistics have been accumulated over many years, particularly in developed countries. In Japan, for example, the *Suisan Jiko Tokubetsu Chosa* (special survey on fishery matters) was being published as long ago as 1894.[1] This survey can be

[1] https://www.stat.go.jp/library/meiji150/shiryo/shiryo28.html

viewed as Japan's first fishery census.

A relative index of resource density called "catch per unit effort" (CPUE = catch/effort) is obtained from this information. Because CPUE is easily calculated, it is used as an important index for understanding the status of resources. However, in addition to resource density, CPUE is also affected by other factors, such as fish distribution, operating season, and differences in fishing equipment. Consequently, CPUE standardization methods and analytical methods for estimating absolute stock abundance have been developed. Examples include virtual population analysis (VPA) using age information (catches by age; Ichinokawa and Okamura, 2014), and the development of a state-space model that serves as a type of stock assessment model (Okamura and Ichinokawa, 2016; Zhu et al., 2017).

Fishery statistics can provide a vast amount of information at low cost. And various methods have been developed for using this information. Therefore, fishery statistics have been widely used as a means of monitoring (assessing) fishery resources. However, fishery statistics have shortcomings. For instance, there are difficulties in quantifying fishing effort, and insufficient information on catches due to closed fishing that arise from the application of strict fishing regulations or bias in fishing grounds and seasons, etc. These factors can cause bias when assessing fishery resources. Thus, fishery-independent monitoring methods are needed.

2-2 Sample-based fishery resource surveys (experimental fishery survey)

The actual conditions of the fishing activities produce bias in fishery statistics. This makes it necessary to conduct sample-based fishery resource surveys that can directly obtain and provide important monitoring information on the characteristics of distribution and recruitment trends by fish species. In Japan, scientific catch surveys using research vessels are conducted by the Japan Fisheries Research and Education Agency, prefectural fisheries experimental stations, and private research organizations, et al. These surveys ascertain the distribution of targeted fishery resources and recruitment conditions by conducting catch surveys at observation points established within survey areas using particular types of fishing equipment within certain periods of time. They also identify the number (density) of targeted resources at each observation point and estimate stock abundance based on it. In these surveys, the survey area, survey period, and fishing equipment used are determined according to the characteristics of the targeted resource. The types of fishing equipment used include trawl nets, basket nets, drift nets, and set-nets, with trawl nets being the most commonly used for quantitative surveys. For example, a frame trawl (Framed Midwater Trawl: FMT, etc.; Miyashita, 2016), which has a quantitative function, can estimate the fishery stock abundance with comparative accuracy by considering collection efficiency. It is widely used in surveys from plankton to fish (Itaya et al., 2009; Oozeki, et al., 2012). Trawl surveys can be classified into surface trawl surveys, midwater trawl surveys, and bottom trawl surveys, depending on the depth at which the net is towed.

Normally, when a research vessel conducts a catch survey, it simultaneously conducts a survey of marine environmental factors—such as water temperature, salinity, and plankton—that are used to identify the mechanisms of resource fluctuation. Periodic surveys of the marine environment have been conducted in the seas surrounding Japan for more than 60 years, creating a vast and valuable store of data for fishery resource research.[2]

However, a single research survey can only obtain information for a limited area and time period. This makes it essential to establish and maintain a cooperative survey system comprising multiple organizations—and to secure continued funding for it—in order to ensure continuous observations over an extensive area of the sea. Both fishery resources and marine environments fluctuate over time scales ranging from several years to several decades, meaning that research surveys can only fulfill their function if they are conducted continuously over a broad expanse of ocean. To accurately identify trends in fishery resources, it is important to skillfully balance the use of information obtained from fisheries and information obtained from research surveys (Zhu et al., 2018).

2-3 Egg and larval surveys

Egg and larval surveys are conducted in countries around the world to identify fish spawning grounds, spawning seasons, and the development of eggs and larvas. The egg production method (EPM) estimates stock abundance (spawning stock biomass) using the estimate results of total egg production. EPM is widely used as a fishery-independent monitoring method. In particular, it is used as one of the stock abundance indexes to assess small pelagic fish resources (Lasker, 1985; Oozeki, 2010). In egg and larval surveys, eggs and larvas are collected using plankton nets, continuous underway fish egg samplers (CUFES), and other instruments at several fixed points in the survey area to classify species and determine abundance (Checkley et al., 1997; Ozeki, 2010). In Japan, egg and larval surveys have been conducted mainly on small pelagic fish species, such as sardines and mackerels, since 1945. Since 1978, the surveys have been conducted continuously in the waters around Japan through a cooperative framework consisting of the Japan Fisheries Research and Education Agency, prefectural fisheries experimental stations throughout the country, and others (Ozeki, 2010).

Although egg and larval surveys can ascertain fishery resource trends directly through

[2] https://www.fra.affrc.go.jp/bulletin/news/fnews56.pdf

scientific and systematic surveys, without reliance on fishing activities, they are predicated on the identification of egg species and require large-scale surveys covering entire spawning grounds. Such characteristics make them very costly. For this reason, they are often conducted only during the main spawning seasons of important economic fish species in some countries and waters.

2-4 Sighting surveys

It is possible to estimate the resource dynamics of marine organisms that swim near the ocean's surface, such as whales and dolphins, through sighting surveys. The first and most important task when conducting a sighting survey is to set a survey course and survey points. Here, it is desirable to design the survey with reference to preliminary surveys and past data on the target organisms (Miyashita, 2004). Ordinarily, a research vessel or aircraft is sent along the preestablished survey course, and various data information—such as the date and time that a target organism was visually observed, the location where it was found, the species name, and the distance of observation—are recorded and used in subsequent estimations of stock abundance (Barlow, 1999). Underwater cameras and videos are used to investigate the conditions of underwater life in rivers and shallow coastal waters, and diving-based sighting surveys are also conducted (Masuda, et al., 2016).

Sighting surveys are often used for cetaceans for their stock abundance assessment, as well as for sea turtles that spawn ashore and salmon that migrate up rivers to spawn (Torao, 2017). However, sighting surveys are applicable to only a limited number of marine species. They also require a great deal of labor and experts with highly specialized knowledge. Sighting surveys also have other problems, including the fact that observations can only be made during daytime, that there is bias in the sea areas of observation, and that errors in species identification can occur when target organisms are at a long distance.

2-5 Tag-release surveys

Tag-release surveys have been conducted since early times. In fact, there are records indicating that salmon were released with ribbons attached to them as long ago as the 16th century. The Hokkaido Fisheries Experimental Station conducted Japan's first tag-release survey on autumn salmon in the Ishikari River in 1917 (Kurogane, 1963). The purpose of the tag-release survey is to estimate a wide range of parameters—such as the movements, seasonal migration routes, growth, spawning grounds, subpopulations, and stock abundance of target organisms—based on location, number, age, and other information obtained from tagged organisms when released into the ocean or a river, and recaptured. Tag-release surveys are widely used as a key means of monitoring that provides scientific grounds for promoting the study and management of fishery resources. Moreover, because tag-release surveys are relatively low-cost, the Fisheries Research and Education Agency, prefectural fisheries experimental stations, and other such institutions continue to use them in their studies of many aquatic species, including tunas, yellowtail, flatfishes, crabs, cetaceans, shrimps, and squids. Tag-release surveys are thus making a significant contribution to fishery resource research.

However, the results of tag-release surveys depend on the information obtained from recaptured individuals. Therefore, survey results may be biased if the recapture rate is low due to deaths caused by the tags, the loss of tags that fell off, or incomplete reporting of recaptured individuals (Kurogane, 1963; Jepsen. et al., 2015). In the case of surveys that use ordinary anchor tags, the only information that can be obtained pertains to the time of the tagged individual’s release and the time of its recapture; what the individual did in between is unknown (Miyashita, 2016). Furthermore, tag-release surveys have a disadvantage in that they are limited to information relating to the tagged organisms only, making it difficult to efficiently grasp the marine ecosystem as a whole.

2-6 Bio-logging

“Bio-logging” is an academic term that combines the words "bio" (organism) and "logging" (to record). It refers to a research method that came from the idea of utilizing data observed from the perspective of animals, rather than that of humans, in environments that exceed the limits of human vision and recognition. Specifically, it is a method of measuring for understanding the behavior of organisms and their surrounding environments by attaching various devices to animals and gathering data.

The attached devices are mainly divided into two types—a data storage type and a data transmission type—depending on the purpose of the research and the target organism. In the case of the former, the device is a recorder (data logger) equipped with various sensors which is attached to the target organism, and data are obtained by the recovered device after data are recorded. In the latter case, a radio-wave or ultrasonic transmitter is attached to the target organism, and then data on the organism's behavior and environment are obtained remotely (Bograd, et al, 2010; Williams, et al., 2019). The transmission type can acquire data in real time by picking up signals sent from the transmitter to a receiver and is particularly suitable for studying the movement, distribution, and habitat of organisms. However, radio waves and ultrasound have a disadvantage. The amount of information they can transmit is limited, meaning that the types of sensors that can be used and the amount of data that can be acquired are also more limited in comparison with the storage type (Williams, et al., 2019).

Recent technological advances have led to the miniaturization of devices, and the range of target organisms has expanded from large organisms to seabirds and small fish as a result. Moreover, various sensors have been developed that make it possible to collect a wealth of data from a diverse range of target organisms. Attaching acceleration sensors, propeller sensors, temperature sensors, light intensity sensors, pressure sensors, magnetic sensors, and video cameras capable of recording images and acoustic information to target organisms makes it possible to obtain information on a variety of study items, including the mechanisms of organisms' diving and foraging behaviors, their physiological states (such as body temperature and heart rate), and their social behaviors (such as group behaviors and parent-child relationships) (Miyashita, 2016; Yoda, 2018). Moreover, it is also possible to obtain information on the surrounding environments experienced by the target organisms, thus bio-logging information may be utilized in ocean and weather forecasting as well. Examples of research here include the use of seabird flight data to estimate the direction and speed of sea winds (Yonehara et al., 2016) and the use of sea turtle-derived observation data in predicting seawater temperature fluctuations in complex coastline seas (Doi et al., 2019). Furthermore, understanding fish behavior through bio-logging provides important insights for fishery management. For instance, a study of the swimming behavior of flounders using bio-logging found that their catch rate was greatly influenced by seasonal changes in their swimming behavior, and that, ultimately, catch data only are highly likely to over- or underestimate flounder stock abundance (Kawabe, 2009).

As is demonstrated above, bio-logging is being applied to a wide range of research fields for various purposes, and its development as a method for observing organisms and the environment is looked to with anticipation. Nonetheless, it also comes with some problems. To name a few, obtainable data are limited to the habitat of the target organism, and only information on a single individual can be obtained from a single data logger. Moreover, data loggers are expensive, the recovery rates for storage-type devices are low, data cannot be obtained unless a signal is received, and the reception range depends on the number of receivers. Sensors, data loggers, and transmitters can also fall off, and so on.

2-7 Acoustic remote sensing

When underwater, sound waves have much lower attenuation than light or radio waves and can reach much farther. Because of this, acoustics are widely used for remote surveys of marine life (called "acoustic remote sensing"). Acoustic remote sensing is mainly classified into "active" and "passive" methods.

(1) Active acoustic surveys

"Active acoustic survey" refers to a method for determining the locations and conditions of marine organisms by sending ultrasonic waves out into the water and then measuring the strength of the sound reflected by organisms and the time it takes to receive the reflected sound. From this survey, it is possible to make speculations about the biological characteristics of target organisms, such as their abundance, size, taxon, and species. Measuring target strength (TS), which is the intensity of acoustic scattering generated by the target species, is essential for making such speculations (Abe, 2010; Amakasu, 2019). TS fluctuates depending on the fish's body length, posture distribution, and swim bladder. The presence (or non-presence), size, and shape of the swim bladder, which is considered to be the main acoustic scattering part, have the greatest influence on TS (Amakasu, 2019). Since fluctuations in TS are a major cause of error in stock abundance estimation, achieving greater accuracy in TS measurement methods is desired.

The most widely used underwater acoustic device for acoustic surveys of fishery resources is the quantitative echo sounder. This device is used particularly in surveys of middle and demersal fish resources, such as the walleye pollock. Because quantitative echo sounders use a sharp downward-facing beam, they have difficulty detecting the sea surface and have a narrow search range. They therefore have trouble measuring surface schools and fast-swimming fish. Moreover, the noise of a moving survey vessel can cause pelagic fish to flee, reducing the reliability of stock abundance estimates. To address these problems, a scanning sonar has been developed that can search the surrounding area at high speed by sending out an underwater acoustic beam horizontally over a wide area. The scanning sonar can search without being affected by the escape responses of fish, and its search range is dramatically larger compared to the quantitative echo sounder.

With advancements in acoustic technology, new underwater acoustic devices have emerged one after another. Examples include the development of a multi-beam sonar that can obtain a view of the seafloor in three dimensions,[3] and the development of an acoustic video camera (imaging sonar) that can produce acoustic images in real time at a high frame rate (Mizuno, 2019). Acoustic surveys are used not only to discern fishery resources but also to visualize ecological characteristics (Miyashita, 2019). Visualization of the spatiotemporal prey-predator relationship and visualization of differences in day/night and seasonal distributions for target organisms are examples (Miyashita, et al., 2004). Furthermore, acoustic monitoring has made it possible to rapidly and quantitatively visualize the spatiotemporal distribution of seaweed beds that maintain the functioning of coastal

[3] https://ideacon.jp/technology/inet/vol42/vol42_new02s.pdf

ecosystems (Shao, et al., 2017).

Although active acoustic surveys can be used over relatively wide areas, they are known to have more difficulty in species identification than other methods. Moreover, bias tends to occur in acoustic surveys when they target isolated fish populations or schools that rapidly change their size and shape. It is necessary to obtain knowledge about the survey area and target organisms through organism collection and environmental surveys before conducting an acoustic survey. In addition, only limited information can be obtained in a single survey. This makes it difficult to obtain a complete picture of resource dynamics in the ocean.

(2) Passive acoustic surveys

Some cetaceans, fish, crustaceans, and other marine organisms are known to emit sounds for various purposes, such as communicating with each other and threatening enemies. Additionally, the sounds produced by marine organisms differ from species to species. This raises the possibility that those sounds can be used as ecological indicators of organisms' existence, behavior, and abundance (Lin, et al., 2018). Passive acoustic surveys are a method of observing marine lives that utilizes those sounds (Mellinger, et al., 2013).

Specifically, this method involves setting up underwater microphones at fixed observation points to record underwater sounds continuously over a wide area. The next step is to deduce information on marine organisms detected—such as the species, location, behavior, and number of individuals—at the observation points. This is done by separating, distinguishing, and analyzing the sounds of specific organisms from underwater sound data obtained from the microphones while referencing previously understood characteristics of the sounds that each species makes (David, et al., 2007). In the past, passive acoustic surveys were thought to provide only qualitative information. However, the development of methods such as the acoustic independent mark recapture method and the point-source density estimation method have made quantitative estimation (e.g., density estimation, creation of distribution maps, etc.) possible. For example, using the acoustic independent mark recapture method has made it possible to estimate the number of dolphins inhabiting the area around an observation point (Kimura et al. 2014).

Submarine cable observation systems have been developed in the seas around Japan to monitor earthquakes and tsunami. These systems are equipped with hydrophones and have accumulated a store of long-term acoustic observation data. According to past literature, the sounds of baleen whales and sperm whales were extracted from underwater sounds collected by the submarine cables and led to the visualization of the whales' appearances and locations (Iwase, 2008). Thus, there are expectations that long-term continuous monitoring of cetaceans moving over large areas will be possible by utilizing the huge submarine observation networks that were developed for monitoring earthquakes and tsunami.

Passive acoustic surveys using animal sounds are advantageous as a method for remote acoustic observation of large marine organisms, from fish to marine mammals, in that they can obtain information on target organisms in a non-lethal manner. If acoustic sensors were placed densely over a wide area of the ocean, they could make it possible to visualize the ecological dynamics and abundance of marine organisms. However, the sound database for marine life remains incomplete, as the sounds of only a very small number of marine species have been identified. Putting passive acoustic surveys into practical use will require achieving even higher accuracy in species identification by improving technologies for removing noise from acoustic data and extracting targeted signals.

2-8 Environmental DNA analysis

Within the water, soil, air, exists DNA from the organisms that live there. Such DNA is referred to collectively as “environmental DNA” (eDNA). Recent technological advances have made it possible to detect minuscule amounts of eDNA easily. Since DNA sequences are species-specific, eDNA analysis can acquire a great deal of information about the organisms inhabiting there. Analyzing the eDNA present in water samples collected from rivers and oceans makes it possible to estimate the presence or absence, species composition, and amount of biomass of aquatic organisms in those waters （Ficetola et al., 2008; Matsuhashi et al., 2016).

The normal procedure for conducting an eDNA survey involves collecting a water sample from the water body being studied, passing the sample through a filter, collecting the DNA on filter paper, and then extracting and analyzing the DNA from the residue (Takahara et al., 2016). There are two main methods of analysis: species-specific detection and metabarcoding. The former involves applying a polymerase chain reaction (PCR) method with species-specific primers to amplify and detect the DNA of a specific target organism in order to make presumptions about its presence or absence (Fukumoto et al., 2015). The latter is a method for comprehensive detection of many species in a taxonomic group. It involves applying PCR with universal primers that can amplify the DNA of species belonging to a certain taxon, reading the DNA base sequence with a next-generation sequencer, and then checking the results against a database (Miya et al, 2015). Each has its advantages. The former is simple, inexpensive, and can easily obtain data providing indicators of the biomass of a target organism. The latter is more costly in terms of its analyses. However, it can provide a large amount of data at once and detect a wide variety of species comprehensively with one analysis.

Environmental DNA analysis is considered to be simpler, less expensive, more efficient, and more environmentally friendly than conventional methods for monitering fishery resources, such as sighting surveys, sample-based capture surveys using nets and other equipment, and acoustic surveys. Because species identification is based on DNA information, it does not require the complex techniques of morphological species identification. It also has the advantage of being easily able to detect endangered species and species with low population densities (Takahara et al., 2016). Moreover, eDNA analysis makes it easy to continue a survey for a long period of time, as its processes are simple and do not require specialized skills. With these qualities, eDNA analysis can obtain spatiotemporally dense biological information and can be used as a survey method for forming big data. Research based on eDNA analysis has been rapidly expanding in recent years. Such research has produced a wide range of findings relating to the detection of fish species, ascertainment of species composition and fish population size (biomass), estimation of fish migration routes and spawning grounds, estimation of fishery stock abundance, and understanding the extent of alien species invasions (Yamamoto et al., 2017; Ushio et al. al., 2017; Takahara et al., 2012; Berry et al., 2019).

However, eDNA is advected and diffused by water flows and decays as a result of decomposition, and thus many key aspects—such as its state of existence, degree of diffusion, and persistence time in water—remain unknown. For this reason, the spatial range and temporal resolution that can be detected by a single water sampling survey tend to be unclear (Yamamoto et al., 2016). In other words, it is often unclear when and where detected DNA was released by the target organism. Additionally, because DNA from dead individuals can also be detected, the concentration of eDNA and the number of individuals of the organism do not have a simple proportional relationship, making it difficult to accurately estimate the number of individuals. A research team from the National Institute for Environmental Studies recently developed a new method for estimating the populations of target organisms based on eDNA analysis. However, its estimation accuracy is still not high, and further research is thought to be necessary (Fukaya et al., 2020). In addition, because eDNA analysis is a form of indirect observation, it cannot obtain information on the age and size compositions of the organisms even when DNA is detected. Furthermore, since species identification is performed based on the DNA information, an adequate database of base sequence information for various species must be developed.

3. Summary

As can be seen from the above, various methods are available for monitoring fishery resources. Table 1 provides a brief overview. Various organizations use these methods to conduct surveys that attempt to observe the actual conditions of fishery resources both directly (e.g., sighting surveys and bio-logging) and indirectly (e.g., fishery statistics and environmental DNA analysis). Each method has its advantages and disadvantages, and there is no single perfect method that satisfies all needs. This makes it necessary to first fully understand each monitoring method's characteristics and then to utilize a specific method or the best combination of methods according to the purpose. Traditionally, fishery statistics have been used alone as basic data when attempting to understand changes in fishing activities and catch trends. However, when predicting stock abundance or clarifying mechanisms in population fluctuation, it is best to use data that combine fishery statistics and sample-based fishery resource surveys. Sighting surveys, tag-release surveys, and bio-logging are suitable observation methods when monitoring the ecology and behavior of predetermined target organisms, while acoustic remote sensing and eDNA analysis are suitable for monitoring a wide range of biological resources over an extensive area. Sample-based fishery resource surveys, egg and larval surveys, tag-release surveys, and biologging involve the collection or direct use of target organisms. On the other hand, sighting surveys, acoustic remote sensing, and eDNA analysis provide information on target organisms in a non-lethal manner through remote observation or water sampling and are expected to contribute significantly to surveys of endangered species.

Table 1: A comparison of fishery resources monitoring methods

Monitoring method	Obtained information	Advantages	Disadvantages
Fishery statistics	・Catch ・Fishing effort	・Vast amount of data ・Various analysis methods	・Bias in fishing grounds ・Difficulty in quantifying fishing effort
Sample-based fishery resource survey	・Distribution of targeted resource ・Number (density) of targeted resources	・Comparability with past data ・Availability of samples permits various scientific research ・Supplement to fishery statistics	・Dependent on survey seasons and sea areas ・Poor applicability to wide-area surveys
Egg and larval survey	・Spawning ground ・Spawning season ・Development of eggs and larvas	・Independent from fishing ・Permits scientific research	・Difficulty in identifying egg species ・High survey cost
Sighting survey	・Distribution of target organism ・Number of target organisms	・Permits scientific research ・Availability on underwater cameras and video	・Limited species of organisms (cetaceans and other animals that rise to the surface) ・Labor-intensive ・Surveys are limited to daytime ・Species identification can be limited by conditions of visibility
Tag-release survey	・Movement of target organism ・Migration route ・Growth ・Spawning ground ・Stock abundance, etc.	・Comparatively low survey cost ・Long-term accumulation of survey data	・Dependent on characteristics of recaptured individuals ・Low recapture rates ・Lack of information on time between the individual's release and recapture
Bio-logging	・Behavior, ecology, and physiological information of target organism ・Information on surrounding environment, etc.	・Various sensors can be attached ・Applicable to various fields (oceanography, fishery, climatology, etc.)	・Information is limited to the habitats of the organisms used ・High cost of logging devices ・Low recovery rates of tagged device ・Reception range depends on number of receivers, etc.
Acoustic remote sensing (active/passive)	・Biomass ・Distribution of organisms (location of appearance) ・Environmental information ・Seabed conditions, etc.	・Allows surveys over relatively large areas ・Remote, non-lethal survey	・Difficulty in identifying species (active) ・Need to build a model for conversion to biomass ・Incomplete organism sound database (passive)
eDNA analysis	・Detection of fish species ・School size ・Migration route ・Spawning ground ・Stock abundance ・Extent of alien species invasion, etc.	・Simple, inexpensive, efficient survey ・Environment-friendly ・Permits wide-area surveys ・Obtainable of spatiotemporal biological information	・Unclear on detect spatial range and temporal resolution ・Difficulty in estimating populations ・Uncertainty of age and size compositions

4. Future Prospects

Goal 14 of the Sustainable Development Goals (SDGs) adopted at the United Nations Conference on Environment and Development is "conserve and sustainably use the oceans, seas and marine resources for sustainable development." One of the goal's targets is the scientific management of fishery resources. Various measures and systems are being utilized to manage fishery resources scientifically. They include the introduction of a Total Allowable Catch (TAC) system, the establishment of area closure and seasonal closure for fishing, the development of sea farming and marine ranching, and the application of fishing eco-labels. Ascertaining the actual conditions of fishery resources through monitoring methods provides the basis for establishing these measures and systems. However, current monitoring methods for fishery resources remain inadequate, and further development and improvements are desirable. It is necessary to analyze the disadvantages of each monitoring method and then to study practicable strategies with focus on the points that can be improved. For example, in order to deal with the low recovery rates of tagged devices, a disadvantage of bio-logging, measures should be taken to develop and popularize technology for data collection in real time via remote reception. For acoustic remote sensing, completing the database of sounds made by species is desirable. While for eDNA analysis, there is a need to develop a method for estimating the number of individuals based on DNA concentration. At the same time, while the monitoring of fishery resources is usually undertaken by public research organizations, collaboration with private companies and private organizations is also desirable. Research institutes could, for instance, work with private shipping companies to install echo sounders on merchant ships or have merchant ships conduct water sampling surveys for eDNA analysis. Such steps would make it possible to more efficiently obtain information on biological resources over a broad area and further expand the scope and frequency of fishery resource monitoring.

Meanwhile, because fishery resources tend to fluctuate depending on environmental factors (e.g., water temperature, ocean currents), it is also important to monitor such marine environmental factors as water temperature, ocean currents, salinity, and plankton. Utilizing the data obtained through these surveys will make it possible to explain the mechanisms in population fluctuations of marine resources. I believe we will move closer to achieving the sustainable use of fishery resources if we gain knowledge of current conditions through each monitoring method, predict future conditions based on the understood fluctuation mechanisms, and, at the same time, comprehend the actual circumstances of IUU (illegal, unreported, and unregulated) fishing to prevent overfishing. I believe the establishment of a monitoring network at the marine ecosystem level—that is, extending from marine organisms to marine environments—can be expected in the future.

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