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Smart Technologies in Fisheries: Innovations in Monitoring, Management, and Sustainability

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Abstract This study mainly explores the core challenges during the global fishery transformation period, such as overfishing, deterioration of marine ecology, environmental pressure from aquaculture, and the problems of data deficiency and lag in fishery management. Why can intelligent technology become a key breakthrough for the sustainable development of the fishery industry? I have summarized the main technologies and application scenarios of intelligent fishery, such as Internet of Things sensing, artificial intelligence and big data, remote sensing and blockchain, as well as their practical application effects in resource assessment, water environment monitoring, IUU fishing identification, and precise aquaculture. I have also clarified the roles of these technologies in protecting fishery resources, improving production efficiency and industrial chain benefits, as well as their comprehensive impacts on the sustainability of the fishery environment, economy and society. Additionally, I have also paid attention to related issues such as international governance norms, national policy supervision and data ethics. I have also discovered that factors such as technology, economy and others have hindered the popularization of intelligent fishery, possibly exacerbating the uneven development of the industry. Intelligent fishery will integrate deeply with "Fishery 4.0" and AIoT. This study aims to combine technological innovation with inclusive development, people-oriented concepts and ecological protection, and promote the deep integration of technology with fishery systems and interests relations, so as to fully unleash its potential. This study provides practical theoretical and practical references for building an intelligent sustainable fishery industry globally.

Keywords Intelligent fisheries; Sustainable fishery development; Artificial intelligence; The Internet of Things; Fishery management

1 Introduction

In recent years, the global fishing industry has been in a critical transformation stage. Overfishing has put wild fish resources at risk, and climate warming and marine pollution have further damaged the ecological foundation of the fishing industry, directly affecting food security and the livelihoods of fishermen. Aquaculture has alleviated the pressure of fishing, but it also faces issues such as diseases and environmental burdens; while fishery management has always lacked data and the data is lagging behind, making resource assessment and law enforcement very difficult.

permeated every aspect of the fishing industry, becoming an important helper in the transformation of the industry. In marine fishing, electronic monitoring and remote sensing equipment can accurately collect data related to fishing, which is very helpful in combating illegal fishing (Barreiro et al., 2025); in aquaculture, the combination of the Internet of Things and artificial intelligence can automatically monitor water quality and identify fish diseases, not only improving the farming efficiency but also reducing carbon emissions (Lv, 2025); in the supply chain， the combination of blockchain and the Internet of Things can clearly trace the entire fishing process， and a new model of intelligent fishing is gradually taking shape.

In real-world settings, bringing intelligent technologies into use is rarely just a matter of choosing the most advanced option on offer. Much of the existing literature concentrates on what these tools can achieve in principle, but pays less attention to how they perform once they are introduced into established social arrangements and management routines. When projects move from the planning stage into everyday operation, practical difficulties tend to appear quickly. High initial costs, uncertainty over data ownership, and reluctance to change long-standing management habits often turn out to be more disruptive than expected, slowing implementation or, in some cases, causing projects to stall altogether (Barreiro et al., 2025).

Regional differences add another layer of difficulty to this process. In some areas, relatively advanced and integrated applications are already being tested in practice, while in others progress is still constrained by basic infrastructure limitations. This uneven development has gradually exposed gaps in access to digital tools and has prompted ongoing discussion about who is able to use new technologies and who ultimately benefits from them (Wang et al., 2025). In this context, focusing only on technological advancement is unlikely to bring about stable outcomes. What matters more in practice is whether these tools can be adjusted to fit local ecological needs, governance arrangements, and social conditions, allowing them to become part of routine work rather than remaining symbolic additions with limited real impact.

This study will explore the resource, environmental and governance challenges faced by global fisheries, and analyze the reasons why intelligence and data-driven approaches have become the key to sustainable development. At the same time, it will review the current intelligent technologies related to fisheries, analyze their application value and the path of integrating them into an eco-oriented management system, and combine cross-border cases to provide theoretical and practical references for building an intelligent sustainable fishery.

2 Common Intelligent Technologies in the Fishing Industry and Their Operating Modes

2.1 Internet of things and sensing technology

In day-to-day work, many fish farmers still rely on fairly familiar routines to judge what is happening in their ponds. They walk along the edges, watch the color of the water, pay attention to any strange smells, and now and then pull up a few fish to check their condition. This way of working has been passed down for a long time and is not completely unreliable, but its limitations are obvious. It requires time and constant presence, and much depends on whether someone happens to be on site. Changes that take place late at night are especially easy to overlook. When water temperature drops suddenly or dissolved oxygen falls quickly, the signs are often noticed only after the fish have already been affected, leaving little chance to react early. Precisely because of this, the Internet of Things and sensing technologies have gradually been introduced to the livestock farming sites. In simple terms, some devices are installed in fish ponds or near-sea farming areas to enable them to "keep an eye" on the water conditions. Data such as water temperature, pH value, and dissolved oxygen, which previously required manual monitoring, can now be continuously recorded. Even minor fluctuations are not easily overlooked (Huang and Khabush, 2025). After preliminary processing of the data, it will be transmitted to the platform. Farmers do not necessarily have to go to the pond; they can roughly grasp the situation from their offices or mobile phones (Huang and Han, 2025).

In real settings, this type of system is rarely tied to just one kind of farming environment. How it is used often depends on where it is deployed. Along coastal waters, it tends to function mainly as an early warning tool. Events such as red tides can be picked up earlier than before, giving managers at least some time to respond instead of reacting after the fact (Adnan et al., 2025). In inland ponds, however, the focus is more on everyday control. When water quality starts to shift, equipment like aerators or water exchange systems can be activated in time, helping fish and shrimp remain in relatively stable conditions. There are also cases where monitoring does not stay in one fixed location. With the use of mobile devices, for example unmanned boats, areas that were previously difficult to cover can now be checked more easily, and the overall monitoring range becomes wider. Of course, there will also be problems in actual use. Sensors may be blocked by mud or algae, and power supply instability occurs from time to time. These are not the "ideal conditions" mentioned in the technical promotion, but some targeted improvement methods have emerged now, such as self-cleaning probes and solar power supply. In the end, it is precisely because these data come more promptly and in greater detail that fishery management can gradually shift from "based on experience" to a more precise approach.

2.2 Artificial intelligence and big data

Collecting the data is merely the first step. What really causes headaches is how to determine what to do next when faced with a bunch of numbers. At this point, artificial intelligence and big data analysis come into play. They are more like a "background system", specifically responsible for identifying patterns from the chaotic data and providing relatively clear instructions. Nowadays, many breeding farms are attempting to use models to predict changes in water quality or assist in assessing the risk of fish diseases (Idoko et al., 2025). Some situations that were previously difficult to explain, such as sudden deaths of fish and shrimp, or oxygen deficiency in the water body in the morning, can also be detected in advance through data backtracking and trend analysis, thereby reducing losses. This does not mean that the problems can be completely avoided, but at least it is no longer necessary to make remedial efforts after the fact.

If artificial intelligence is directly linked with existing Internet of Things systems, which is often described as AIoT, its use is no longer limited to simple monitoring. In practice, this connection allows farming operations to respond more flexibly to what is actually happening in the pond. For example, feeding does not have to follow a fixed schedule. It can be adjusted according to how fast the fish are growing and how actively they are feeding. In some cases, different pieces of equipment can also be connected and respond automatically when conditions change (Chen and Huang, 2025).

These adjustments do not attract much attention, and taken individually they are easy to pass over. With time, however, their influence on everyday work becomes harder to ignore. Tasks that once required repeated manual handling are now performed less often by hand, feeding decisions are approached with more caution, and the most obvious forms of waste are easier to pick out and keep under control. Gradually, this changes how feed and related inputs are managed, weakening routines that were largely built on habit and accumulated experience rather than deliberate planning (Huang and Khabush, 2025).

Seen from a wider angle, the introduction of intelligent technologies into traditional fisheries is clearly not driven by sudden breakthroughs. Instead, small adjustments are made one after another, and many of them blend into existing practices without drawing much attention. What stands out is a change in how decisions are made. Choices that once relied almost entirely on personal judgment are now more often compared with data before action is taken. The process is slow and uneven, but it is beginning to influence everyday operational decisions in a steady way. In the fishing industry, AI can process data such as vessel tracking and satellite images to achieve intelligent identification of fishing vessels and fish stocks, estimate the catch volume, and detect traces of illegal fishing. Globally, AI can uncover the patterns of fishing activities and provide a basis for regulation and policy-making. However, the application of AI is constrained by issues such as data acquisition and standardization. It requires collaboration among fishery administrators, fishermen, and developers, and adaptation to actual needs, in order to transform AI from experimental applications into reliable fishery information systems.

2.3 Synergistic integration of remote sensing, unmanned systems and blockchain technology

Remote sensing, unmanned systems, and blockchain are integrating with the Internet of Things and AI to build a complete intelligent fishery system. Satellite remote sensing and drone images can make up for the shortcomings of on-site monitoring. Combined with ship data and AI, it can enhance the scope and efficiency of fishery supervision. Drones and unmanned ships are becoming increasingly common in the fishing industry and are quite practical. For instance, fishermen often use them to inspect fish cages and estimate the number of fish, and the operation is very convenient. As a result, the coverage of the Internet of Things becomes wider, and staff no longer need to frequently go to sea, which not only reduces operational risks but also significantly saves monitoring costs. What's more noteworthy is that if multiple devices work together, even those more complex monitoring tasks can be successfully handled (Idoko et al., 2025).

Blockchain has also begun to find its place in fisheries, although its role is sometimes easier to see in practice than in theory. Put simply, it offers a way to make fishery-related data more reliable and easier to trace. In seafood trade, for example, information can be recorded from the moment the catch is landed through processing and finally to the market. Once these records are uploaded, they cannot be altered at will and can be checked whenever needed. When blockchain is used together with the Internet of Things and artificial intelligence, it becomes harder to falsify records or hide inaccurate reports, and in real applications this combination has shown promising results. Similar blockchain-based IoT systems are not limited to fisheries. They have also been tested in agricultural production, where production data can be securely stored and protected from tampering. This makes certification of agricultural products more transparent, as the supporting evidence is clearer and easier to verify. In some pilot projects, such as quota trading, these systems have played an additional role by helping keep supply chains more stable and reducing the risk of disputes. For small-scale fishers in particular, this kind of transparency can translate into more predictable income and better livelihood security (Nandhini et al., 2025).

3 Innovation in Fishery Monitoring under Intelligent Technologies

3.1 Rethinking fishery resource monitoring and population assessment

For many years, estimates of fish populations were often based on broad impressions rather than solid numbers. In quite a few regions, surveys were carried out only occasionally, data accumulated at a slow pace, and by the time results were finally compiled, conditions in the water had already changed. This was especially common in small-scale fisheries, where staff numbers were limited and technical support was hard to come by. The shift away from this situation did not happen all at once. In the early stages, new monitoring tools were tested only in a small number of pilot sites and attracted little attention. Their value became clearer only over time. Today, monitoring is no longer restricted to short field surveys conducted once in a while. In some coastal fisheries, artificial intelligence–based image recognition has gradually entered routine work, making it possible to identify and count fish and invertebrates directly from images. In the Pacific region, for instance, a cloud-based platform has been developed that can recognize more than 600 coastal fish species. By handling large volumes of uploaded images, the system has sped up resource assessments and, in some cases, helped relieve pressure caused by shortages of specialists and long-term data records (Figure 1) (Kharabsheh and Bdour, 2025).

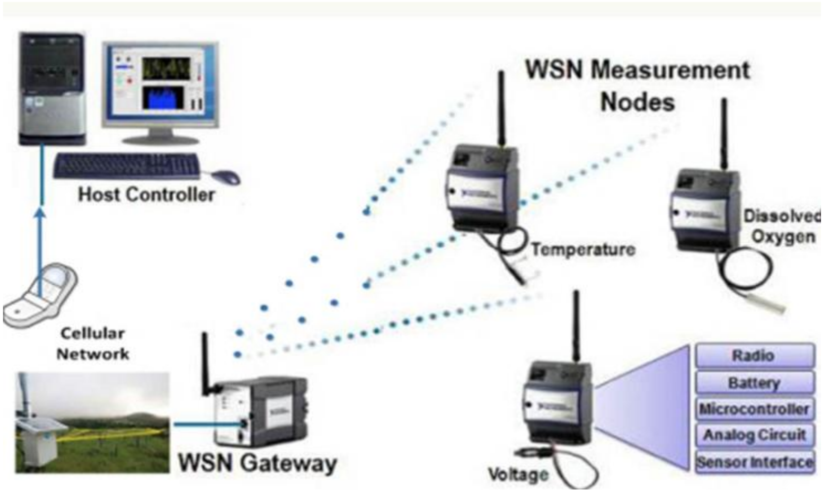

Figure 1 Illustration of the communication method embedded in the developed system (Adopted from Kharabsheh and Bdour, 2025)

These approaches are not only useful for species that are easy to spot. Evidence from Europe suggests that they also work for organisms that tend to remain hidden. Studies on Norwegian lobster populations combined underwater video, environmental DNA, and image analysis to locate individuals and their burrows directly in the field. Compared with earlier methods, this combination produced population estimates that were closer to actual conditions. At the center of these systems is not a single technology, but the ability to bring different types of information together. Images, catch records, and spatial data are uploaded to a central cloud platform, where learning algorithms extract indicators such as species composition and size structure. In many developing regions, this level of integrated analysis was previously difficult to achieve. If sensor networks and prediction models are added to the process, assessments can move closer to reflecting the condition of the wider ecosystem, rather than isolated snapshots.

3.2 From fish ponds to oceans: real-time monitoring of water environments

In many cases, changes in water environment monitoring came quietly rather than through any clear turning point. Across aquaculture operations, long-used practices were usually kept in place, with new tools added around them rather than replacing them outright. Low-cost sensors were introduced gradually and, over time, became part of everyday management routines. Once installed in ponds, they began to record basic conditions such as water temperature and dissolved oxygen on a continuous basis. Compared with earlier methods that depended heavily on manual checks, this approach reduced repeated measurements and, when problems occurred, left behind records that could be reviewed later instead of relying solely on experience or recollection (Kharabsheh and Bdour, 2025; Sharma, 2025).

As data continued to build up, the way they were used began to change almost without being noticed. In some systems, monitoring gradually moved beyond simply recording conditions and started to offer rough indications of survival rates, or to issue warnings when key indicators were approaching critical levels. Under relatively stable management settings or controlled trials, reported accuracy can be very high, sometimes above 99%. In a few cases, systems are also able to react automatically to changes in weather by adjusting water quality parameters, which has helped ease daily workloads and made routine management a little more efficient for farmers (Baena-Navarro et al., 2025). At the same time, results are far from consistent. Differences in data quality, local environmental conditions, and management practices still play a major role, and performance can vary markedly from one farm to another.

Related approaches are now being tested outside pond-based aquaculture as well. At a larger scale, projects such as those carried out in the Gulf of Aqaba have combined sensor networks with machine learning tools to track water quality in real time and assess the risk of coral bleaching. Available reports suggest that this setup has maintained monitoring effectiveness while reducing overall costs by around 30% (Kharabsheh and Bdour, 2025). Satellite remote sensing has also been drawn into this process. Although its spatial resolution is limited and the results are not always precise, it remains one of the few workable options for observing large marine areas at the same time. When satellite data are used together with nearshore sensor observations, monitoring begins to span multiple scales, gradually linking aquaculture management with broader assessments of ecosystem conditions.

3.3 Intelligent detection of illegal, unreported, and unregulated fishing

When it comes to dealing with illegal fishing, intelligent technologies are often appreciated because they make monitoring possible over a much wider area than manual inspection alone. In real situations, however, using these tools is rarely simple. Machine learning systems are typically applied to vessel movement data alongside satellite observations, with AIS signals used to identify routes or behaviors that appear unusual in timing or pattern. In Southeast Asia, for instance, studies have relied on vessel trajectory data to highlight zones where the risk of illegal fishing is relatively high, rather than to confirm individual violations outright (Sharma, 2025).

Some systems go a step further by assigning risk scores to vessels, suggesting whether they may be operating outside permitted waters. Others focus on identifying particular patterns, such as extended periods of loitering, through tools sometimes described as a "fishery prediction guardian." These systems can issue timely alerts that help enforcement agencies decide where closer attention may be needed (Sharma, 2025). They are not intended to replace inspectors working on the ground, but rather to filter large amounts of information and highlight cases that warrant further checking.

Despite these advances, a number of limitations remain difficult to avoid. One long-standing issue is that some vessels intentionally switch off their AIS transmitters, leaving sizeable gaps in monitoring coverage. To work around these blind spots, researchers have increasingly experimented with remote sensing and the joint use of multiple data sources. The INSURE system deployed in Ghana is often cited in this context, reporting an identification accuracy of around 91%. Even so, existing studies indicate that close to 75% of observed vessels still lack AIS records, which highlights how incomplete current surveillance efforts remain. As monitoring tools continue to be introduced more widely, other challenges have also become harder to ignore. Access to reliable data is uneven across regions, and false alarms occur often enough to remain a practical concern. In response, researchers have begun exploring a range of possible directions, including the combination of different image sources to enable more continuous, all-weather monitoring, as well as the use of blockchain-based tools to strengthen the credibility of operational records. These approaches are still being tested, but they suggest several possible paths for improving future responses to illegal, unreported, and unregulated fishing (Sharma, 2025).

4 How Intelligent Technologies Are Reshaping Fishery Management

4.1 Decision support systems and the shift away from pure experience

For a long time, fishery management followed a fairly familiar routine. Records were written by hand, figures were arrange and checked later, and decisions were usually made after the fact rather than during the fishing process itself. In some situations, by the time all the notes had been reviewed and compared, the season was already nearing its end. This way of working was not useless, but it was slow, and it rarely reflected what was actually happening at sea at that moment. The shift away from this approach happened step by step. Decision support systems were not introduced as a complete replacement from the start. Instead, they were added gradually and used alongside existing practices. As they improved, information that had once been scattered across different logbooks and reports began to appear in one place. Today, electronic logbooks, vessel position data, and catch records can be viewed together on a single platform, making it easier to follow fishing activity as it unfolds. The iFIMS system used by members of the Pacific Nauru Agreement is a typical example. With fishing volumes available almost in real time, routine assessments are now faster, and much of the repetitive manual data work has been reduced (Agmata and Guðmundsson, 2025).

These systems do not have to stop at basic data integration. In some cases, machine learning and image analysis have been added, making it possible to extract indicators like catch per unit effort automatically. This opens the door to more flexible management responses, such as temporarily closing certain fishing areas when environmental conditions change. At the same time, cloud-based deployment has made two-way communication easier. Fishers upload data, while managers send back forecasts or catch trend charts, which can help crews adjust their schedules. If vessel data and environmental information are further combined, the system may even estimate fishing probabilities, balancing quota control with ecosystem protection. That said, technology alone does not guarantee good management. Without clear governance arrangements, shared data standards, and proper privacy protection, even the most advanced system can fail to function as intended. Effective fishery management still depends on coordination across sectors and on fitting these tools into existing legal and institutional frameworks.

4.2 Moving toward more precise fishing and aquaculture practices

In recent years, fishing and aquaculture have started to look a bit more like carefully managed farming systems, although this change has not followed a single path. The underlying goal is fairly straightforward: increase output while avoiding extra pressure on natural resources. How this goal is approached, however, differs noticeably between capture fisheries and aquaculture. In capture fisheries, artificial intelligence is generally used as a point of reference rather than as a substitute for human decision-making. In routine practice, managers often look at historical catch records together with basic ocean conditions—such as variations in water temperature or salinity—to form a rough impression of where fish may be gathering. These models are not meant to remove uncertainty, and in practice they do not. What they tend to offer instead is a way to narrow down options, limit avoidable bycatch, and give managers more room to adjust quotas as conditions change (Agmata and Guðmundsson, 2025). At the same time, monitoring gaps that have existed for a long time are gradually being reduced. In many coastal areas, information on species distribution and market trends is now collected more regularly, while the combined use of remote sensing and vessel tracking has made coordination across regions more manageable, especially as marine ecosystems continue to shift at a faster pace.

Aquaculture follows a different logic. Here, the emphasis is less on prediction and more on keeping daily conditions within a manageable range. Sensors are usually installed for long-term use, continuously recording environmental indicators, while automated systems respond by fine-tuning feeding schedules and oxygen supply.

This does not mean that farming conditions are always optimal, but it does help keep biomass estimates more stable and reduce obvious feed losses. Ideas such as “intelligent fish farms” or automated production lines have become increasingly familiar, and in some cases digital twin technologies are already being used to simulate farming environments and coordinate equipment through cloud platforms. These approaches are not without limits. High upfront costs and a lack of trained personnel remain common obstacles. Still, with careful system design, wider adoption is possible, and over time such tools may contribute to both higher productivity and more environmentally responsible aquaculture practices.

4.3 Intelligent platforms and collaborative governance

An intelligent fishery platform should not be understood as nothing more than a data collection system. In real settings, it often plays a much broader role. It becomes a place where different groups are brought together. In several offshore fisheries in the Pacific, for example, monitoring systems were created through joint efforts by government agencies and local communities. Rather than dismantling existing arrangements, these systems were designed to work with local practices. Community-generated data were also incorporated, which made it easier for groups that are geographically dispersed to share experience, compare situations, and coordinate their actions. At a broader level, this type of cooperation is sometimes described using a “four-spiral” framework, which links academia, industry, government, and civil society. The emphasis is on moving innovation, financing, and training forward together, while connecting fishery management with wider concerns such as climate adaptation and food security.

Platforms built in this way rarely stay the same once they are put into use. As people interact with them, their role often shifts. Experiences from local fishery committees in Chile, as well as co-management practices in the Catalan Sea, suggest that bringing different stakeholders into the process can make a real difference. Community involvement helps preserve local autonomy, while state oversight remains in place, and tensions over how marine space is used become easier to handle. Seen from this angle, intelligent fisheries are not shaped by technology alone. Participation, mutual trust, and day-to-day cooperation matter just as much. When these elements are missing, even carefully designed systems tend to remain on paper rather than becoming part of practice. This is why future research and policy may need to spend less time on technical performance by itself, and more on how intelligent systems fit into participatory governance arrangements, with data managed in a fair and transparent way to support long-term social and ecological sustainability.

5 Application of Artificial Intelligence Video Monitoring in Fisheries

5.1 Application background, scenarios and system composition

In fishery management, the observer system has always faced a practical contradiction: when people go on board, the number is limited, and thus the coverage is naturally restricted; but if cameras are used instead and the footage is recorded and then reviewed by humans, with more videos, people will actually become even busier and unable to handle it all manually. Especially now, many long-distance and line-trawl fishing fleets have installed electronic monitoring equipment, and the amount of data is so large that it is almost impossible to fully process it manually. It was precisely under the circumstances where "there weren't enough people but there was too much data", that artificial intelligence video surveillance began to be taken seriously. Some research teams attempted to use deep learning models to directly process onboard videos, allowing the system to automatically identify fish species and judge fishing behaviors. The entire process hardly relied on manual intervention (Figure 2) (Khiem et al., 2025). Currently, such systems have been applied in various scenarios, such as nearshore resource assessment, deep-sea species observation, and even the automatic counting of crustacean catches from small fishing vessels. In the end, its key lies not in "taking videos", but in converting continuous videos into standardized data that can be used for management.

In routine use, this kind of system does not feel especially complicated to operate. Cameras mounted on fishing vessels simply record what happens during normal work, and the footage is later handled in the background rather than being reviewed manually. During processing, the models go through the video by identifying what appears on screen, following movement patterns, and sorting different elements into broad groups (Khiem et al., 2025). On a number of Australian longline vessels, this setup has already become part of regular practice. Fishing records are produced as trips are still underway, so crews no longer need to wait until returning to port to complete their logs. Other systems place their emphasis elsewhere. AI-RCAS, for instance, is built around speed rather than post-trip analysis. Instead of waiting until fishing operations are finished, it delivers information while work is still in progress. This makes it possible for crews and managers to respond to on-board situations as they unfold, adjusting actions in real time rather than relying only on later reviews. Beyond deck-level cameras, underwater imaging and towed cable observation devices are also used to turn raw video into useful population data. With these components working together, a clear pattern has emerged in recent applications. Most fishery AI video monitoring systems now follow a structure in which data are collected at the front end and processed centrally at the back end, a setup that has gradually become the common approach in practice.

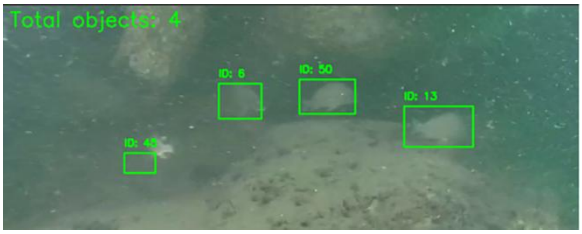

Figure 2 Fish counting results show the number of objects with bounding boxes in each frame (Adopted from Khiem et al., 2025)

5.2 Actual performance in resource assessment and law enforcement

Judging from how these systems are currently used, AI-based video monitoring can generally cope with everyday resource assessment tasks, even though its limitations are well recognized. In most routine situations, it provides information that is sufficient for basic management needs. On Australian trawler vessels, for example, early versions of the models produced catch counts that were broadly consistent with manual observations, with only small differences between the two approaches (Khiem et al., 2025). Similar technologies have also been applied to monitoring black cod populations and documenting underwater coral habitats, often without requiring major changes to existing equipment or operating procedures. Once the systems are in place, day-to-day operation tends to be relatively uncomplicated.

The value of video-based monitoring is often felt most clearly during enforcement work. Conventional observation relies largely on on-site personnel, and records usually have to be reviewed after the fact, which can take time. By comparison, AI-supported systems operate continuously in the background, so footage does not need to be examined from scratch once an issue arises. When real-time analysis is added, these systems can also support the management of total allowable catch limits and, in certain situations, help flag fishing activity occurring in areas where access is restricted. However, this technology is not perfect. In situations with insufficient light or turbid water bodies, the recognition effect will significantly decline; for some uncommon species that are also caught incidentally, the model is prone to make incorrect judgments. Therefore, if the goal is long-term and stable supervision, relying solely on algorithms is clearly insufficient. Establishing a dedicated quality control process is still necessary.

5.3 Key technical points and promotion potential

Looking at how AI video monitoring performs in everyday use, its effectiveness often comes down to a series of quite ordinary details. Model choice plays a role, but it is rarely decisive on its own. In routine operation, the size of the training dataset and the amount of effort put into labeling tend to have a visible impact on results. Under suitable conditions, recognition accuracy for some commercially important species can reach close to 90%, although this level is usually the outcome of repeated adjustment rather than a one-off installation (Khiem et al., 2025). Practical experience also shows that decisions made during system design can matter just as much as the algorithm. Camera placement is a typical example. It is easy to treat as a secondary concern, yet it strongly affects both species recognition and the stability of body length estimates (Baker et al., 2025). Hardware adds another layer of constraint. Smaller fishing vessels often have to work with low-power devices, while deep-sea observation platforms, despite stronger computing capacity, still struggle with the sheer volume of video data that needs to be processed.n terms of wider application, AI video monitoring appears easier to adapt than many other digital technologies. Approaches first tested in Australia are now being discussed for use in other offshore fisheries, and in some cases have also been applied to recreational fishing. At the same time, core detection modules are becoming more standardized, which makes it possible to use similar systems across aquaculture facilities, nearshore fisheries, and mixed-catch monitoring settings (Khiem et al., 2025; Baker et al., 2025; Al-Abri et al., 2025). Even so, technical readiness alone rarely leads to smooth adoption. Questions around privacy, access to data, and coordination among different stakeholders tend to emerge during implementation. In practice, setting clear goals for how systems are meant to be used, building open and comparable benchmark datasets, and involving fishers directly in system design often prove more helpful for real-world uptake than continuing to focus only on improving algorithm performance (Afrifa-Yamoah, 2025).

6 Intelligent Technologies and Sustainable Fisheries Development

6.1 How intelligent monitoring supports resource conservation and ecological restoration

In fisheries management, recent changes are driven less by specific devices than by continuous data collection and use. Previously, data were scattered and infrequent, and problems were often identified only after damage occurred. With the gradual adoption of intelligent monitoring, sensors deployed at sea, on vessels, and around aquaculture sites now regularly record key indicators such as temperature, salinity, dissolved oxygen, and fish distribution. While individual measurements may seem ordinary, together they provide managers with a clearer picture of fishing pressure and help identify areas requiring protection (Li et al., 2025; Lu, 2025). When combined with satellite data and automated analysis, these systems also make illegal fishing harder to conceal, while selective fishing gear has further helped reduce pressure on certain fish stocks (Wang et al., 2025). Although not immediate solutions to overfishing, these tools allow earlier and better-informed management responses.

Marine protected areas follow a different approach, where limiting disturbance is often more important than increasing monitoring frequency. Technologies such as underwater robots, biological tagging, and automated stations enable long-term observation of species behavior and habitat recovery with minimal human interference, providing more stable references for restoration decisions (Masmitja et al., 2025). Management has gradually shifted from reacting to damage toward earlier risk identification, as AI and large-scale data analysis can detect early signs of stock decline (Wang et al., 2025). At the same time, cleaner farming practices and blockchain-based traceability are beginning to influence production choices, placing greater emphasis on long-term sustainability (Li et al., 2025).

6.2 Improving efficiency without focusing on output alone

Innovation in fisheries has never been only about producing more. As resource limits become increasingly clear, attention has shifted toward how efficiency can be improved without adding further pressure on ecosystems. In aquaculture, cloud platforms, Internet of Things technologies, and artificial intelligence are gradually finding their way into everyday management. Feeding and aeration decisions are no longer guided solely by experience. Instead, systems adjust settings in response to real-time data, which helps reduce feed waste and lower mortality under typical operating conditions (Briones et al., 2025). AI-supported biofloc systems provide a practical example of this trend. By automatically fine-tuning culture conditions, these systems help maintain fish health even at relatively high stocking densities, while keeping costs within a manageable range (Alghamdi and Haraz, 2025). They are not suitable for every situation, but they illustrate that improvements in efficiency do not necessarily have to come at the expense of environmental performance.

Changes can also be seen in capture fishing, although they are often less visible. With IoT-based monitoring tools, fishers are increasingly able to plan routes based on real-time sea conditions and market information, reducing unnecessary travel and fuel consumption caused by limited or outdated data (Li et al., 2025). In several developing regions, relatively simple technologies-such as solar-powered equipment and mobile information platforms-have already made a noticeable difference to household incomes (Hungevu et al., 2025; Chandravanshi et al., 2025). Experience from coastal areas of China further suggests that, when systems are designed with care, intelligent technologies can support economic returns while remaining broadly compatible with environmental protection goals.

6.3 Beyond environment or economy alone

Whether fisheries supported by intelligent technologies can genuinely be regarded as sustainable is difficult to judge if attention is placed on environmental indicators alone. In practice, economic and social considerations are closely intertwined and rarely easy to separate. From the environmental side, intelligent systems have been linked to more efficient use of resources, lower levels of waste during farming and processing, improved oversight of illegal fishing through continuous monitoring, and conditions that are more favorable for ecosystem recovery (Wang et al., 2025; Li et al., 2025; Lv, 2025). Economic impacts are also becoming increasingly apparent. Digital tools are helping reduce transaction costs along the supply chain and, in some cases, lowering barriers for small-scale fishers to reach markets. Evidence from China's coastal regions suggests that economic growth and environmental improvement do not always stand in opposition, as long as management arrangements take local circumstances into account (Li et al., 2025).

Social effects, however, are often less straightforward. On the positive side, intelligent systems can help ease labor shortages, improve safety during offshore operations, and provide fishers with more opportunities to participate in management processes (Chandravanshi et al., 2025; Briones et al., 2025). At the same time, several studies caution that unequal access to technology and insufficient policy support may widen existing gaps within the sector or lead to an overreliance on automated systems (Jang et al., 2025). Seen from this angle, the key issue is not simply whether intelligent technologies are available, but how they are introduced, shared, and governed in ways that remain fair, inclusive, and balanced over time.

7 Policy and Regulatory Framework for the Development of Intelligent Fisheries

7.1 International governance and institutional support for intelligent fisheries

International laws and governance initiatives provide the overall direction for the development of intelligent fisheries. Key frameworks such as the United Nations Convention on the Law of the Sea and the FAO Code of Conduct for Responsible Fisheries emphasize monitoring, control, and the use of advanced scientific methods, including digital and AI-based technologies. These principles are further operationalized by regional fishery management organizations through standards such as electronic monitoring and satellite vessel tracking. In addition, the proposed Biodiversity Beyond National Jurisdiction agreement highlights electronic monitoring as a core tool for high-seas protection, offering legal support for the wider adoption of intelligent systems.

At the same time, governance challenges emerge early and are difficult to avoid. As intelligent technologies shape fisheries management, debates quickly focus on system transparency, data access, and decision-making authority. Research shows that data accessibility and transparent processes are essential for trust and accountability. The Global Fisheries Watch initiative illustrates this tension: while it enables public, real-time tracking, it has also raised questions about data ownership and enforcement authority. Similar issues appear in broader international discussions, where AI governance remains fragmented and fishers' practical concerns are often underrepresented. Without parallel efforts to ensure fair access and participation, new technologies risk reinforcing existing geopolitical and economic inequalities.

7.2 National-level policies, regulations and governance practices

At the national level, governments operate between international commitments and everyday management needs. In practice, the pace of intelligent aquaculture development depends less on technological readiness than on whether policies allow flexible yet well-defined use. Many countries have revised aquaculture laws to promote monitoring and traceability, increasing regulatory pressure while also improving efficiency and product quality.

Comparable patterns exist in capture fisheries. Some regions mandate electronic logbooks and vessel monitoring, while others still rely heavily on rigid paper-based systems. These contrasts highlight how regulatory design shapes technology adoption. For example, the United States emphasizes performance outcomes rather than specific equipment, whereas the United Kingdom continues to debate mandatory remote electronic monitoring. Studies suggest that voluntary systems often yield uneven results, making standardized approaches such as "SMART" mechanisms more effective. Evidence from countries like Indonesia and Pakistan further shows that lasting improvements depend on both reliable data and coordination across governance levels. Where legal, administrative, and technical systems are misaligned, effective governance is difficult to sustain (Suherman et al., 2025; Lina and Butt, 2025).

7.3 Data governance, ethical issues and regulatory challenges

The development of intelligent fisheries requires robust data governance frameworks that balance innovation with confidentiality, fairness, and ethical use. AI systems rely on large volumes of vessel, catch, and image data, yet privacy concerns and legal restrictions often limit data sharing. Even where technology is mature, paper-record requirements and strict confidentiality rules continue to constrain digital applications, while dedicated regulatory standards for fishery AI-such as algorithm transparency and accountability-remain underdeveloped.

As intelligent monitoring becomes more widespread, ethical concerns are increasingly visible. Technologies like remote sensing and drones expand regulatory capacity but also raise questions about privacy and data ownership. Governance research emphasizes that fishers and local communities should be active participants in decisions about how data are collected and used, rather than merely serving as data sources (Montana, 2025). At the operational level, weak coordination among institutions remains a key vulnerability. Inconsistent terminology and unclear standards can create confusion once data flow across agencies. Studies warn that rigid quota rules or poorly designed data systems may generate unintended ecological and social effects, underscoring the need for cautious, preventive policy approaches rather than overreliance on rapid technical fixes (Radi et al., 2025). Ultimately, successful governance depends not only on technology, but also on whether intelligent systems function fairly and effectively in real-world practice.

8 Challenges, Future Trends, and Prospects

The adoption of intelligent technologies in fisheries and aquaculture is constrained by a combination of technical, economic, and operational factors. These barriers slow implementation and may widen existing development gaps within the sector. Technically, intelligent systems depend on reliable sensors, networks, and data transmission, yet many aquaculture sites and small-scale fisheries are located in remote areas with weak infrastructure, making long-term maintenance difficult. Economically, high upfront costs, uncertain returns, and limited financing channels—especially in developing countries-restrict wider uptake. Operationally, limited digital literacy among fishers and managers, along with continued reliance on paper records and the lack of recognition of third-party data, further hinders implementation. As a result, fisheries digitalization cannot be treated as a simple technological upgrade, but must account for the diverse capacities and needs of different actors.

Looking ahead, intelligent fisheries are likely to evolve toward deeper integration between "Fishery 4.0" and AIoT systems. By combining artificial intelligence, the Internet of Things, and edge computing, future systems will increasingly link production, monitoring, processing, and marketing. In aquaculture, intelligent fish farms are expected to become more common, using sensors, computer vision, and digital twins to optimize water quality and feeding in real time, while edge computing helps address connectivity challenges in remote areas. At the same time, advances such as deep-sea intelligent aquaculture will continue to emerge. Successful implementation will depend heavily on cross-disciplinary and cross-institutional cooperation, enabling data sharing, regulatory coordination, and alignment with real production needs. Future research is also expected to move beyond small-scale pilots and focus more on long-term impacts and governance frameworks that support sustained application.

Despite these challenges, intelligent fisheries still hold significant potential to support sustainable development when technological innovation is combined with inclusiveness, people-centered approaches, and ecological protection. Existing applications of IoT monitoring, AI analysis, and blockchain traceability have already improved efficiency, reduced waste, and increased transparency, while helping small-scale fishers access data and markets more effectively. AIoT and marine intelligent technologies can support adaptive management and ecological restoration by providing real-time information on resources and fishing intensity, and Industry 4.0 approaches may further reduce environmental impacts. Nevertheless, intelligent technologies are not a universal solution. Their long-term value depends on lowering application costs, improving digital skills, and establishing fair data-sharing mechanisms that reflect the realities of small-scale fisheries. Ultimately, intelligent technology is a tool for transformation, and its effectiveness rests on how well it is integrated into institutional reforms and evolving interest relationships within the fishery sector.

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Conflict of Interest Disclosure

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