Fisheries monitoring: Management models, compliance and technical solutions

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Abstract: Monitoring must be considered within the broader context of fisheries management, which in turn is a part of a mosaic of multiple ocean and natural resource uses, including environmental conservation. Monitoring has a role to play in all aspects of fisheries management, including those related to the sustainable management of the resource, the economic performance of the fishery and the distribution of benefits from the exploitation of the resource and use of the environment. An immense challenge faced by management is that of finding cost-effective monitoring methods. Given its multiple roles, resources must be allocated to monitoring against competing but often related needs from other management related activities such as licensing, planning and legislation, policy formulation, marketing, surveillance and enforcement and research. This paper examines the challenges of fisheries monitoring and the extent to which solutions lie in (i) finding appropriate fisheries management models and plans, (ii) understanding the fishers motivation for compliance, and (iii) technical solutions.

1 INTRODUCTION

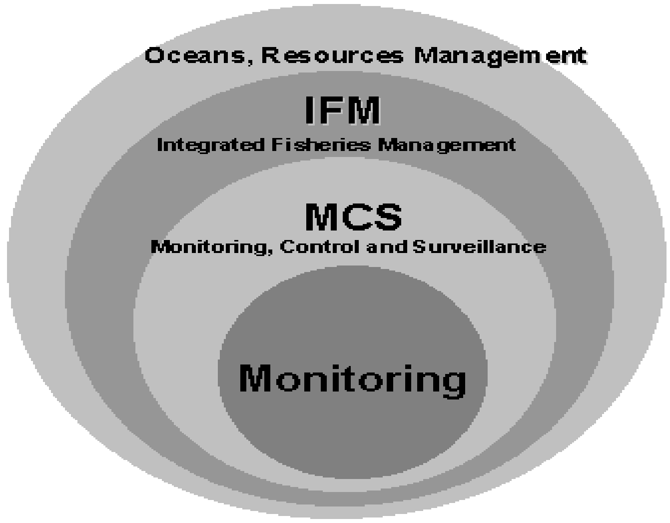
Fisheries are just one of the users of ocean and aquatic system resources, albeit the user considered to be having the greatest impact on the oceans (Second London Oceans Conference, 1998). Oceans and resources management form the broader frame for fisheries management (Fig. 1), and, within this, monitoring, control and surveillance are key functions. Monitoring as a function, therefore, must be integrated with other functions and activities which are much more encompassing in their scope. Indeed, monitoring is only relevant in the larger context of fisheries and oceans management.

By *integrated fisheries management* we refer to the rational exploitation of fisheries resources based on notions of sustainability efficiency and equity.

We take our definitions of *monitoring, control and surveillance* (MCS) from those established and accepted at the 1981 International MCS Symposium sponsored by the Food and Agriculture Organization of the United Nations:

1. *Monitoring* involves the collection, measurement and analysis of fishing activity, including: catches, species composition, fishing effort, discards, area of operation, etc.
2. *Control* involves the specification of terms and conditions under which resources can be harvested, which are normally contained in fisheries legislation and other arrangements (national, sub-regional, regional).
3. *Surveillance* involves the checking and supervision of fishing activity to ensure that national legislation and terms, conditions of access, and management measures are observed.

Figure 1: Fisheries management and monitoring within the wider context of oceans management



Monitoring fisheries operations to assist fisheries management faces formidable technical challenges due to the combined vagaries of a fluctuating and cryptic target resource in its dynamic environment and a mobile exploitation activity. In the majority of fisheries, especially those in tropical developing countries, the large number of species involved, the multiplicity of fishing gears and the widely dispersed landing sites make monitoring, enforcement and compliance measures extremely difficult. Huge costs and already overburdened institutional mechanisms are entailed. High seas and straddling stocks fisheries present extra difficulties and these constraints have paved the way to looking at less costly and more innovative monitoring solutions.

In short, fisheries MCS programmes are required to be effective and efficient within the operational capacity of those charged with their implementation. They must also have legitimacy and, above all, must by relevant and integrated with the fishery being managed.

Fisheries monitoring is undertaken for several purposes. It can help detect extreme events and trends such as the violation of standards, the extent of discards and bycatch. It helps to establish baseline data from which to measure changes. Monitoring also forms the basis for assessing current conditions and helps establish cause-effect relations. Finally, one of the most important purposes of monitoring is to inform in the resolution of fisheries conflicts.

Monitoring data can be many and varied and could include: fish catches, fisheries habitats, number of fishers, census of gear, verification of fishing vessel registration, catch verification and activities that have displaced fisheries activities (e.g. pollution, cages/large fishpens). Monitoring data, the facility with which it may be gathered and its costs, are highly dependent not only on the management regime but also on the nature and scale of the fishery. Thompson (1980) demonstrated some of the differences in a table from which Figure 2 is extracted.

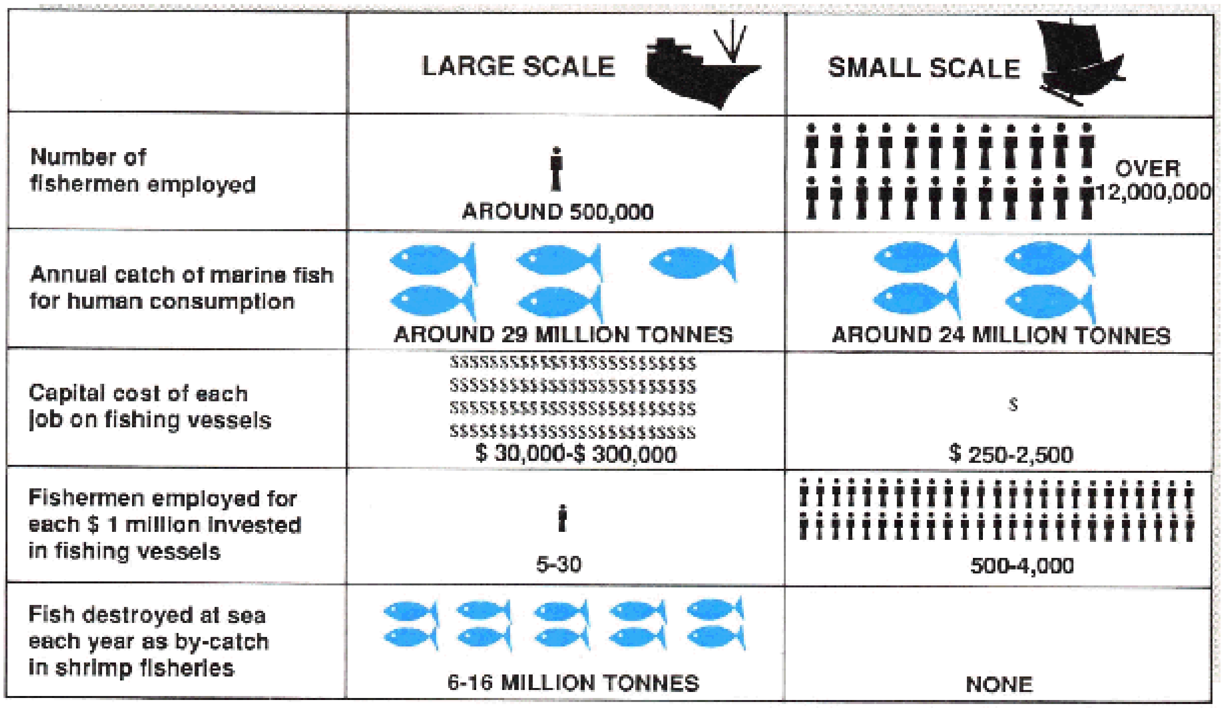


Figure 2. Some dimensions of the differences between small and large scale fisheries, at a global scale (extracted from Thompson 1980).

2 WHY INTEGRATED FISHERIES MONITORING?

To be effective, fisheries monitoring and enforcement must be integrated within fisheries management and fisheries management integrated within the larger scheme of marine resource and environment management. Put another way: *"If you can't measure it, you can't manage it."*. Fisheries monitoring and enforcement has two essential components: (a) the acquisition and collation of information about fishing activities; and (b) the inducement, on the basis of information obtained, of compliance by fishing vessel operators with desired modes of conduct (Moore 1993).

Fisheries monitoring and the collection of data to provide scientific advice for management are inextricably linked in fisheries management and to management in other sectors. Significant attempts have been made through the Code of Conduct for Responsible Fisheries (FAO 1995) to integrate the various elements of fisheries and aquaculture for sustainable practices. Monitoring and the cost-effective collection of good fisheries data are vital parts of the integration and are mentioned in Article 7.7 of the Code itself and in Article 2.4.4 of the Technical Guidelines for fisheries management under the Code.

Furthermore, if not done effectively, monitoring can even contribute to the failure of fisheries management. For example, 3 out of 7 hypotheses for management failure are related directly or indirectly to monitoring, namely data uncertainty, simple models and complexity (Smith 1998) (Table 1).

Fisheries face increasingly complex problems and these cannot be resolved without good monitoring information. For example, the overall catching capacity of commercial fishers has increased tremendously due to improved fishing gear and an increase in the number of boats in commercial fisheries. A large proportion of the catch, that is, about a third of all landings, are discarded. By-catches amount to 27 million t annually (Alverson *et al.* 1994). In addition, as stocks have become more stressed, small and immature fish are being targeted. To monitor these trends requires data collection that addresses the questions of bycatch and discards explicitly, in addition to the usual collection of retained catch data.

Outside the fisheries sector, most aquatic resource systems are subject to many different uses which place various pressures on them. These may result in lower water quality, decreases in system productivity, and outbreaks of toxic algal blooms which make fish unsafe for human consumption. Monitoring systems must be integrated into such multi-functional frameworks to protect human life and the sustainability of the aquatic resource base.

Table 1. Hypotheses for the failure of fisheries management. The hypotheses marked in bold are those in which monitoring plays a significant role.

Hypothesis	Example
Folly	Tuchman (1984): *"... perverse persistence in a policy demonstrably unworkable."*
Data uncertainty	Graham (1956): *"inherent limitations of ... fishery statistics..."*
Simple models	Walford (1961): *Fishing "cannot be understood out of context from the intricate system of their biological environment."*
Lack of ownership	Beverton and Holt (1957): *Perfection of regulation will require "some modification of .. individualistic and competitive approach."*
Complexity	Wilson *et al.* (1994): *The "complexity and perhaps chaotic nature of the biological environment" makes management intractable.*
Institutional frailty	Holt and Talbot (1978): *"Institutions are imperfect."*
Greed	Ludwig *et al*. (1993): *"Short-sightedness and greed of humans underlie difficulties in management."*

Source: Smith (1998)

A further consequence of the multiple uses of aquatic environments is that they are managed by and are of interest to, a host of agencies. The various players have a stake in the effective exploitation, conservation and management of fishery stocks. In every country, a host of government agencies are given marine and fisheries mandates which sometimes overlap. These include agencies whose functions are related to environment and natural resources, agriculture and fisheries, science and technology, minerals and petroleum, economic planning and finance, transportation and communications, national defense, maritime police, local government and foreign affairs. Furthermore, non-government organizations (NGOs) and the private sector are increasingly getting involved in the matter of governance and management of fisheries resources. Integrating even the minimum amount of monitoring information collected across such diverse agencies is an enormous challenge. A first step would be to identify the key data sets to be integrated.

With the increasing pressures on fisheries, fisheries monitoring can entail heavy costs (Hersoug and Paulsen 1996) and this at a time when the profitability of fisheries is usually reduced through heavy fishing. Clearly, MCS costs should naturally not exceed national revenue for the fishing industry. Nevertheless, costs of MCS can approach and even exceed these values. In one fishery in the United States, for instance, the national agency spent $80 million on monitoring and surveillance of fishing operations which only collected $51.5 million (Sutinen 1987 in Hersoug and Paulsen 1996). In another case, the cost of a modern enforcement programme for the tuna fishery of a small coastal state like Costa Rica was estimated at approximately 50% of the expected revenues (Lepiz and Sutinen 1985).

Furthermore, costs of monitoring have increased sharply as fisheries have become more heavily exploited. In Malaysia, the costs of monitoring, enforcement and compliance have increased from US$3.1 million in 1976-80, to US$16.63 million in 1986-90, and to US$32.2 million in 1991-1995; these correspond to 5%, 16% and 21%, respectively, of total fisheries expenditure (Kuperan 1994, Abdullah *et al*. 1998).

Considering the links between research data collection and monitoring, we note that much fisheries resources monitoring is carried out through high technology research. For example, oceanographic fieldwork has traditionally meant going to sea in ships. In recent years, it has expanded to include such activities that may require a ship for a short period but then continue independently. The value of programme and equipment integration has been recognised in the United States where, between 1984 and 1997, the University-National Oceanographic Laboratory System undertook a major fleet modernisation and replacement programme. No single agency could have contemplated any part of the programme in isolation (Pittenger 1997).

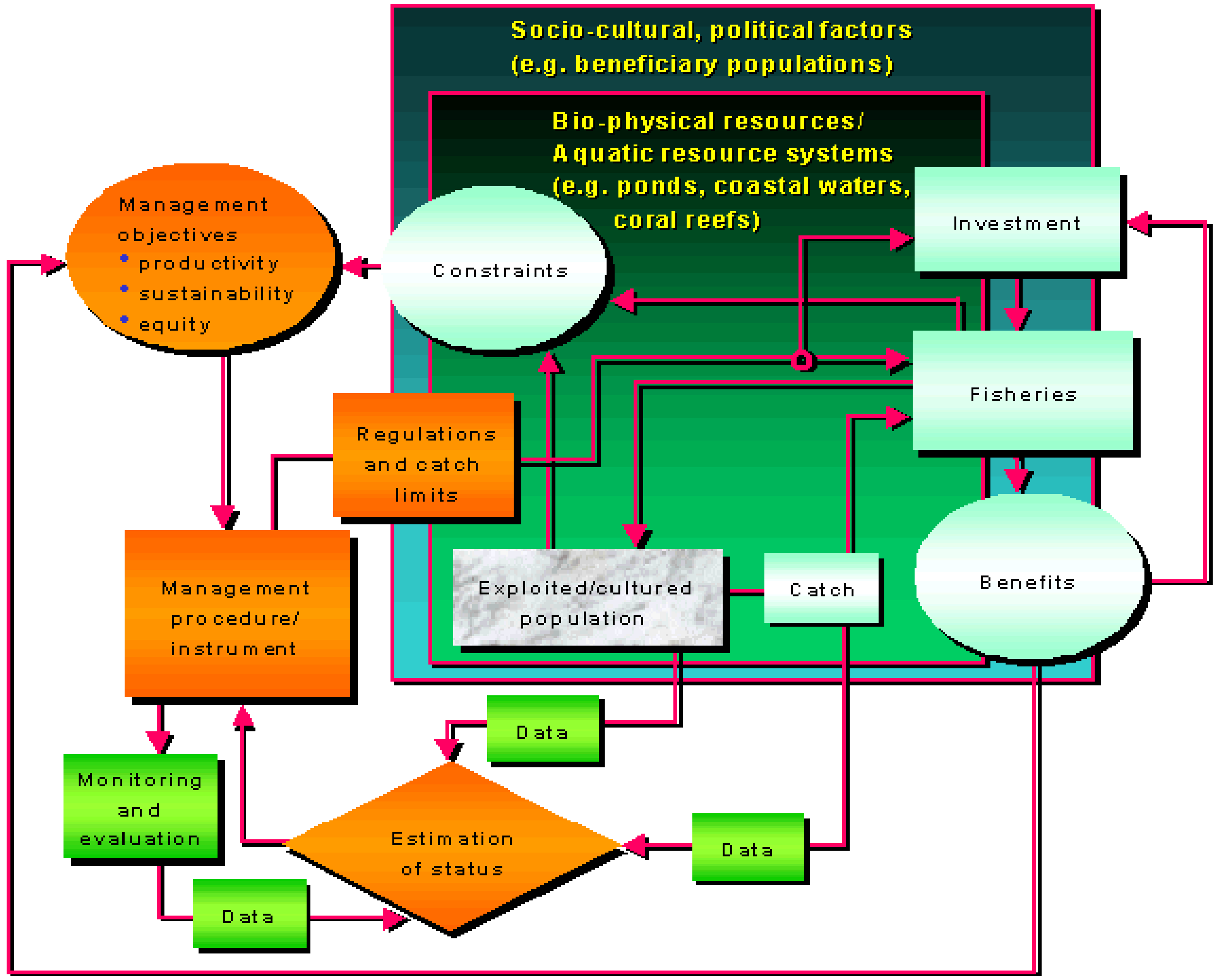
In summary, monitoring is important to help prevent failure of fisheries management that faces increasingly complex problems. However, given the potentially high costs of monitoring, solutions lie in choosing appropriate fisheries management methods which can be efficiently and effectively monitored, a better understanding of fishers motivation for compliance to the management arrangements and technical solutions which can lower the costs and produce more accurate monitoring information.

3 FRAMEWORKS AND APPROACHES TO IFM: MANAGEMENT-ORIENTED PARADIGM

Integrated fisheries monitoring (IFM), as with all functions of fisheries management, including research, is dictated by the type of management system in place and must be changed when the system management changes. A good example of how fisheries management changes is when a change in fisheries monitoring occurs in response to fisheries management adopting an individual transferable quota scheme after managing by a total allowable catch. The collection of monitoring data will shift from a focus on overall landings, say at the landing ports, to greater attention to individual landings and trading in quotas.

Just as de la Mare (1998) recommended that fisheries science generally should be considered within a management oriented paradigm (MOP), so too we consider that fisheries monitoring must be considered within a MOP. This involves comprehending the whole system of fisheries and their management institutions, not just its parts such as monitoring, the resource and the economics of the fleets. Management objectives and procedures have traditionally been viewed as outside the purview of fisheries science. Smith (1998) lamented that fisheries science did not extend to cover the scientific study of management, warning that such a lack of focus on the whole of fisheries would leave fisheries science ineffective in the future as in the past. So too with fisheries monitoring.

Figure 3. Management oriented paradigm showing the relationship between functions in fisheries management (modified from de la Mare (1998)).



The MOP approach for any function consists of: measurable management objectives; a management procedure based on decision rules; assessments based on specific data and methods and a prospective evaluation of the management procedure using performance measures (de la Mare 1998). The fisheries system needs to be studied as a whole, not just as its parts. As with any other system or structure, sustainable management systems have to be designed to get the most benefits at commensurate costs. A modified version of a fisheries system that is based on a management-oriented paradigm is presented in Figure 3.

When applied to monitoring functions instead of research, other management-related activities need to be considered, including licensing, planning and legislation, policy formulation, marketing, surveillance and enforcement. Monitoring systems, compliance behavior and legitimacy have to be taken into account. Furthermore, monitoring systems need to be codified in law to provide full legitimacy. Good compliance by fishers can make a big difference to the cost effectiveness of monitoring. Conversely, monitoring can be designed to check for compliance. In either case, an understanding of what leads to compliance can be important to management and monitoring.

3.1 Compliance behavior and legitimacy

Potentially, a management-oriented approach for fisheries activities should positively influence fishers' compliance behavior. Fishers make interesting subjects for the study of compliance. They are subject to numerous regulations and constraints, yet they offer opportunities, often out of sight of others and the law. Fisheries violations are often the result of deliberate choice. Therefore, the behavior of fishers offers good cases with which to test the role of deterrence, legitimacy and other factors that explain compliance, as well as to suggest better and more targeted monitoring and surveillance systems.

Achieving compliance in regulated fisheries is both costly and difficult. Expenditures on enforcement commonly constitute the largest cost element in fisheries management. Low rates of compliance and high enforcement costs can threaten the viability of fisheries regulation and make accurate monitoring very difficult. Such difficulties justify the need to assess the cost-effectiveness of traditional enforcement measures, and test alternative models of compliance behavior.

According to Parsons (1993), Canadian and other studies suggest that, generally, in fisheries, crime pays. The probability of detection is generally perceived as low (<10%) and penalties are low. Hence, the combined probabilities of detection, apprehension and arrest, and the likely penalty to be levied are so low that fishermen perceive a positive net return from fisheries violations. The combined effect of increased and improved MCS activities, and increased penalties should, over time, change fishermen's perceptions about the net return from fisheries violations.

Further, Parsons (1993) concluded that another dimension to fisheries enforcement, too often ignored, is education. Greater emphasis should be placed on educating and informing fishermen, processors and the judiciary of the rationale for particular fisheries regulations, the benefits to all of compliance and the serious effects of overfishing.

Studies on fishers operating in Malaysia, Indonesia and the Philippines (Kuperan and Sutinen 1998) postulated that four factors are likely to affect compliance decisions by the individual fisher; the amount of illegal gain or benefit; the expected penalty; moral obligation and social influence. In any typical population of fishers, some 5% to 10% of fishers tend to violate chronically and flagrantly and enforcement using coercive methods is the only control mechanism in this case. Non-compliance by the vast majority of fishers is on a small-scale and is often inadvertent or opportunistic and can be controlled by non-coercive methods.

Kuperan and Sutinen (1998) found that the basic deterrence model for compliance behavior is a weak model. They suggested that stronger alternatives are 'moral legitimacy' and 'social influence', or institutional or community-based arrangements that ensure compliance. The 5% to 10% 'hard-core' violators tended to be more alienated from the fishers' community (e.g. migrants, new entrants, non-fishers who take it up part-time).

3.2 Community based approaches.

In many developing countries in recent years, we have witnessed a trend towards community based approaches in traditional or artisanal fisheries. These approaches appear to overcome some of the shortcomings of the traditional deterrence model by focusing on social influence as well as education. The idea of monitoring fisheries resources and controlling the catch is well developed within many community based systems where the lack of formal management laws or regulations does not necessarily mean open access regimes are in place. Rather, customary regimes and other local regimes are commonplace.

Community based systems operate on the following precepts: (a) fishing communities are the primary stakeholders; (b) traditional resource users have property and management rights; (c) self-regulation is the norm; and (d) indigenous methods are in place. The traditional schemes are being integrated with national level systems in fisheries co-management (Pomeroy and Williams 1994), and with adoption of monitoring and surveillance practices as well. One example is the Orion community based coastal resource management scheme in Bataan, Philippines (van Mulekom and Tria 1997). Monitoring is done through a fisherfolk based patrol, in collaboration with the municipal police. The *bantay dagat* (sea guard) team has a small patrol boat, from which it monitors fishers activities at sea. Revenues from fines are allocated to fund patrolling expenses.

In open inland water systems in Bangladesh, local management groups are organised to manage oxbow lakes (local name: *baor*) fisheries in western Bangladesh. All fishers according to gear type in the group operate as teams and elect a leader (Middendorp *et al.*

1996). Each year, a committee is formed from these leaders, and is responsible for the operation and unity of the group.

3.3 'No force' approach

Another approach, called the 'no force' approach, is used by the South Pacific Forum Fisheries Agency (Moore 1993). This is a low cost approach, especially with respect to monitoring, and is now being applied in other parts of the world. Licensing of foreign fishing operations is a significant dollar earner in many developing countries, especially small island developing states (SIDS), but net benefits to the coastal state has not kept pace with increased costs to the fished state and increased fees to the distant water fleets. Substantial costs to both sides are involved in policing fishing operations in exclusive economic zones (EEZs). Surveillance and physical enforcement costs can easily outstrip the financial benefits derived from licensing and, faced with this dilemma, many SIDS have sought new techniques to ensure compliance with their national laws by foreign vessels. Significant progress has been made in developing cooperative means of compliance control particularly at the regional level.

Such a 'no force approach' was established in 1986 by the South Pacific Forum as a regional MCS scheme. A 'register' collates the following information on a region-wide basis: (a) foreign fishing vessels operating in the region; (b) their characteristics and catching potential; (c) their historical catches and (d) fishing areas. Access arrangements and management systems are then designed based on catching potential rather than the actual catch, thus reducing pressures on the information-gathering and verification process. Primary reliance is based on self-reporting by the vessels themselves. With respect to compliance control, cooperative efforts are in place, e.g., regional cost-sharing where physical enforcement is still necessary. `No-force' enforcement methods include: 'good standing' and the threat of blacklisting of the complying and erring fleet, respectively, and the 'flag state responsibility' approach.

The register is an invaluable databank that can be used for the purpose of monitoring and economic research on the fishing fleets operating in the region and as a source of information for national fisheries administrators faced with licensing decisions for individual vessels. It also provides the whole basis for surveillance operations under regional defense and surveillance cooperation programmes. The register is now the centerpiece for regional cooperation and enforcement in the South Pacific region. An innovative Vessel Monitoring System (VMS) tracks the movement of fishing vessels (Brown 1994).

In the past half-decade, however, the Pacific island countries have changed the development strategy for their tuna fisheries from a rent maximization approach to an approach that entails developing their own "locally-based" tuna industries. How this new development strategy could affect the future of regional cooperation and monitoring should be further explored (Schurmann 1997).

3.4 Advocacy approach

Advocacy approaches to monitoring and surveillance have been demonstrated in several fisheries over the years, notably by activist NGOs such as *Greenpeace*. The catchy messages and information produced by these groups capture the public's imagination and are often powerful in revealing certain fishing practices, in changing the views of the public, and thereby the positions of the industry and government on fisheries management. In August 1996, for instance, *Greenpeace* raised public awareness on the extent of overfishing in North Pacific fisheries, and how "factory trawlers" have been "wasting away" 700,000,000 lb. of fisheries products a year (Stump and Batter 1996). These advocacy's are usually accompanied by well-planned media campaigns.

3.5 Oceans policy approach

Several countries are changing their whole marine management regime through higher level oceans policies. These have a strong flow-on effect to fisheries management and monitoring and can assist the integration of fisheries monitoring.

Australia is moving towards a more integrated approach to maritime monitoring and surveillance with the release of its 1998 Oceans Policy (Environment Australia 1998). The policy introduces Regional Marine Plans, provides more support for civil society surveillance and awareness, and provides for more fisheries officers, amended fisheries laws and efforts to reduce incursions by foreign fishers.

In April 1995, Canada's Department of Fisheries and Oceans (DFO) merged with the Canadian Coast Guard (CCC) creating one of the largest civilian marine organisations in the world. The new vision of the restructured DFO is "To be a world leader in ocean and aquatic resources management." The 1997 Oceans Act required DFO to lead the development of a National Oceans Management Strategy (DFO 1997). In fisheries, this builds on an already strong base of MCS, including extensive at-sea observer programmes and a strong scientific programme as described by Parsons (1993).

This section has argued that a suitable framework for fisheries monitoring is a management -oriented paradigm for the fishery. This approach allows integration of monitoring and other systems such as research into the management arrangements and shows how their design and effectiveness largely depends on the management model adopted. Compliance studies indicate where management regimes fail and how greater use of social and other non-traditional deterrence measures are recommended. Community based approaches, `no-force' regional arrangements and full national MCS systems integrated into a complete oceans or marine policy all assist fisheries management's tasks.

4 TECHNICAL SOLUTIONS

The frameworks of regional, national and community-based management described above are all reliant on many technologies for their implementation. Likewise, a change in the technical capability can provide new opportunities for better monitoring and/or more cost effective monitoring of national, regional or local fisheries.

One method for integrated monitoring of the state of fisheries has been the use of global and national stock assessments and status reports. Such reports as the FAO State of World Fisheries and Aquaculture (FAO 1998), the global assessment of by-catch and discards (Alverson *et al*. 1994), the US annual stock assessments (National Marine Fisheries Service 1997), and the Australian status reports (BRS 1998) are examples of high level monitoring tools which provide managers, politicians, fishers and the public with a report card on the state of the fisheries.

These reports would not have been produced without the many stock assessments now made possible by greater research efforts and with greater access to computing and electronic communication around the world.

Sometimes a technical fix to a fisheries management problem can change the scale of monitoring challenges drastically. One such case in point is that of the eastern Pacific tuna-dolphin problem. Dolphin bycatches in tuna fisheries have been at international centre stage in the past decade due to keen US interest plus a strong environmental constituency (Cullet and Kamerie-Mbote 1996). In the eastern Pacific, tuna schools are closely associated with dolphins. In the 1950s and 1960s, bycatches of dolphins by tuna vessels amounted to several tens of thousands of dolphins per year. Due to subsequent technological improvements by the industry and regulatory action both by the US and the international community, however, dolphin mortality dropped dramatically to 3,600 in 1993 (Cullet and Kamerie-Mbote 1996).

As many governments seek to bring down the costs of fisheries management, monitoring costs are continually under review. Cost-effective solutions to monitoring complex fisheries are continually being sought.

One field of monitoring which has been quite successful in developing robust, scientifically valid and cost-effective monitoring methods is that of the assessment of the status of coral reefs and their fisheries. These are particularly difficult and complex systems to describe. High-powered and expensive research survey methods have been used as the basis for developing simplified approaches requiring fewer resources and less time to accomplish useable survey results. One of these is the ICLARM Aquanaut survey method (McManus *et al*. 1997), based on several more complex methods (English *et al*. 1997). In the Aquanaut method, professional divers undergo two to three days survey training and are certified on the basis of this training to undertake surveys. Data are compatible with the global coral reef database, ReefBase (ICLARM 1998). Before the development of these and other methods, monitoring of coral reef fisheries and habitats was not possible in any cost-effective way, depending as it did on a few well-studied reefs which were the sites for scientific research.

The realisation of the overall impact of trawling on fisheries stocks and habitats has led to more monitoring of its effects in many countries. Any changes in trawling practices will lead to major changes in monitoring efforts related to this relatively unselective method of fishing which is one of the most pervasive. Trawling affects an area equal to half (53%) of the world's continental shelves each year according to the most recent study by Watling and Norse (1998), as cited in a news release by the *Ocean Voice International*. Trawl gear not only catches marketable species but also kills non-target species and can damage the sea floor. The fishing industry and researchers are designing and testing gear and fishing methods with low habitat damage (e.g. fish traps, longlines) and more environmentally friendly and selective trawl gear. Industry-developed bycatch reduction devices will benefit from the cooperation of industry, research and management personnel (Rogers *et al*. 1997). Greater emphasis on protected areas management, however, is leading to the establishment of no-trawling zones in some fisheries, to permit recovery of seabeds and to protect biodiversity.

We still lack cost-effective methods for monitoring many small-scale fisheries in both developed and developing countries. Little attention has been paid to developing these methods in recent times, even though the plight of the small-scale fisheries, especially in developing countries, is worsening. Even trawl fisheries data are frequently missing or stored and not analysed in many countries (Silvestre and Pauly 1997). In Asia, a seven-country project led by ICLARM is now seeking to provide better database storage and analytical tools for the monitoring of trawl fish stocks. Extensive use is being made of computers and the Internet to conduct the project.

5 CONCLUDING REMARKS

As the demands on fisheries resources become greater and the problems of fisheries management become more complex, we will be facing escalating needs for good fisheries monitoring data. Monitoring is only relevant in the broader context of fisheries management, which in turn is but a part of a mosaic of multiple ocean and natural resource uses, including environmental conservation.

Inadequate monitoring may cause failure in fisheries management due to data uncertainty, use of too simple models, or lack of appreciation of the complexity of fisheries problems. Fisheries monitoring, however, can entail heavy costs that may be beyond the resources of individual states. To achieve a balance, appropriate models and plans towards an integrated approach to monitoring will need a management-oriented approach for the fishery.

Among others, a management oriented approach to monitoring should seek to positively influence fishers' compliance behavior and go beyond basic deterrence strategies and into stronger long-term alternatives such as moral legitimacy and community based arrangements. Non-compliance of fisheries rules and regulations may be controlled by non-coercive methods that are built on education, moral obligations and social influence. Community based approaches likewise operate on precepts of customary management regimes where fishing communities are the primary stakeholders and self-regulation is the norm. A 'no-force' approach, which may be implemented on a regional level, relies on a databank or register and where access and management arrangements are based on catching potential rather than the actual catch. Moreover, environmental NGOs have been successful in raising greater public awareness and effecting favorable fisheries policies through an advocacy approach, sometimes based on direct monitoring of the fishery. All these models, aligned within a broader oceans or marine management framework, have the potential to ease the tasks of the fisheries manager and redirect monitoring efforts. Such redirection is necessary to prevent the management task from becoming too complex with the greater interaction between fisheries and other aquatic resource users.

Technical solutions offer new opportunities for better and more cost-effective monitoring. Stock assessments and status reports provide decision makers with relevant guides on the overall state of the fisheries. Low-cost and scientifically valid monitoring methods are continually being sought; an example being the assessment of the status coral reef ecosystems through the Aquanaut survey method. Monitoring the impacts of trawling has led to the growth of technologies that address the adverse impacts of trawling on fisheries stocks. However, there is an urgent need to develop more cost-effective methods for monitoring small-scale fisheries in both developed and developing countries.

Monitoring has a role to play in all aspects of management, including those related to the sustainable management of the resource, the economic performance of the fishery and the distribution of benefits from the exploitation of the resource and use of the environment. Exercises such as this Conference are a step forward towards better understanding and integration of goals, objectives and methodologies of fisheries monitoring.

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Stock assessment of target species

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Abstract: The management of fish stocks and fisheries depends crucially on the availability of reliable stock assessments. More specifically, a useful assessment usually must include reliable estimates of the quantity of fish in the stock, its age and/or size composition, its rate of renewal (recruitment and growth), and its rate of mortality (by fishing and by other causes). Typically these estimates are derived from two sources; research surveys and data from commercial fishing operations, combined with biological knowledge from targeted research programmes. In recent years, however, the reliability of assessments has been criticised in many regions, and unfortunately at least some of the criticisms have some validity. Even more regrettably, the states of fish stocks in many regions are poor or declining, and in many of those cases unreliable assessments are implicated as part of the problem. The serious consequences of what has become known as "the retrospective problem" within the stock assessment community is demonstrated to be widespread and prevalent even in countries which invest heavily in research and stock assessments. The collection of reliable data from fisheries operations is not just a good way, but possibly the only feasible way to correct the anomalies in the data associated with unreliable assessments. Accordingly, the features of data sets, and the biological and fisheries events which may cause a strong retrospective pattern to occur in data sets are examined and improvements to traditional assessment estimates illustrated through the use of high quality commercial data on catches, and on the technology and procedures used in harvesting. To view the value of data from monitoring programmes as simply an opportunity to improve traditional assessments, however, is to undervalue those programmes. Several illustrations are presented of how advice on management and conservation of fish stocks can be improved if assessments expand beyond their traditional catch-at-age basis. Data on the spatial and temporal dynamics of fisheries operations, in particular, may be vital to detecting important trends in stocks and fisheries. Moreover, the singular importance of complete and accurate data from monitoring processes and their contribution to significant improvements in both research surveys and targeted scientific research programmes is illustrated. Finally, contemporary fisheries science and management has

historically progressed beyond single-species assessments and management initiatives, to consider multi-species and ecosystem interactions, and the effects of the physical environment on marine populations. Although outside the subject matter of this discussion, sound monitoring programmes can contribute greatly to our knowledge in this larger framework, as well as contributing to improved single-species assessments of target species.

1 INTRODUCTION

Management agencies have tried a vast array of tools, in their efforts to manage the exploitation of fish stocks. Where agencies have had the management authority for a fishery and sufficient capacity has existed that a fishery had the potential to become over-exploited, management generated restrictions have generally been implemented (e.g. sizes of catches, sizes of fish, total effort, numbers of participants, catches per trip, gear characteristics, bycatches, and just about everything else which could be measured and limited (Mace 1996, Hey 1996). Despite all these efforts at control, fisheries and fish stocks internationally are not thriving (Alverson *et al.* 1994, Meltzer 1994, Alverson 1997, Mace 1997). There are some informative patterns to be observed in this history, however.

Typically, each new management tool comes with great publicity, great expectations, and great promises. However, after a suitable interval in which to evaluate the actual effectiveness of the tool, the initial optimism is replaced with more realistic claims: usually that the measure did some good, but offered no total solution. It has been argued that managers should be adaptive (Walters 1986, Hilborn and Walters 1992), but fishers repeatedly show that they, too can be highly adaptive (Rice and Richards 1996). This dynamic cycle of conservation concern, management measures, and industry adaptation is another common pattern through history.

Rice and Richards (1996) discuss the common dynamic interaction between regulatory regimes and activities of fisheries, highlighting the non-functionality of the dynamics when regulators and harvesters do not share common objectives. Here, we should step back and consider the question of why users and managers should ever fail to share core objectives to begin with? At the most fundamental level, fisheries scientists, management agencies, and resource users all must want viable fisheries in ecosystems which are being sustained. What differs between them is what each believes must be done to achieve those two goals. Hence, we arrive at another consistent feature of fisheries management systems (*sensu* Stephenson and Lane 1995): management measures work best when resource users and resources managers both have confidence in first the evaluation of the present state of the stock(s) and fisheries, and second the measure(s) necessary given that stock state.

Why do one or both groups fail to have such confidence in the evaluation of the stock(s)? There are many candidate reasons. Trade journals are filled with articles illustrating that resource users and managers can have different perceptions of the consequences of a given management measure (for examples from one year's issues of one quite responsible Canadian industry publication, see Mackinson 1998, Pepper 1998, Spisak 1998, Stephenson 1998). Single sector publications can be much more strident. Users feel they are being forced to live under regulatory regimes designed by bureaucrats lacking valid knowledge of the realities of the fisheries. As for confidence in the evaluations of the state of the resources, it is now a "received truth" that stock assessments are at best unreliable and often simply the product of faulty methods applied by incompetents to unreliable data (ex. Martin 1995). Hence, another historical generalisation: to correct any of the major ills in fisheries and ecosystem management, one has to start with the accurate measurement of parameters. Without accurate measurements one cannot even begin to sort out the correct methods and the competent assessors, which is a necessary precursor to the task of creating a single perception of stock status shared by all parties.

This paper describes the value of monitoring programmes to stock assessment. The value is obvious. Monitoring provides data, and data are the raw material for stock assessment. No monitoring - no assessment. Although this appears to be a terminal statement, there is much more to this link between monitoring and assessment. Exactly how have unreliable data contributed to the inaccuracy of past stock assessments, and as a consequence to the crises in the world's fisheries? How widespread is the problem of unreliable catch data? Is it universal, or only characteristic of regions of the world which cannot (or choose not to) invest heavily in fisheries science and management? What are the damaging properties of the historic data sets? This is important because if it were just that fishery data were noisy; then estimates would only be highly uncertain, with large confidence intervals. However, the historic data sets associated with the most problematic assessments may have characteristic pathologies, leading to particularly insidious inaccuracies in assessments using the flawed data. Can such pathologies be improved or even eliminated through effective monitoring programmes?

The value of monitoring programmes to stock assessment does not end with improved data, however. Once the data are reliable, it is possible to evaluate the assessment methods as well. However complex a mathematical assessment model is, it still remains just a series of statements about the biology of the fish, and the operations of the fishery, both converted into mathematical algorithms. The knowledge gained from effective monitoring can make these mathematical expressions better in many ways. This can improve the assessment methods, as well as the data which go into them.

2 THE IMPACT OF POOR CATCH DATA ON ASSESSMENTS

Although researchers constantly plead for good data developments over the past decade have made it possible to quantify just how serious the problems with data quality are. This is of particular importance with regard to inaccuracies in assessments and scientific advice on management deriving from poor quality data on commercial catches.

Since the mid-1980s, the "retrospective problem" in assessments has been receiving much attention (summaries see Mohn 1993, 1999, Mesnil 1995). When one conducts an assessment in year x, using catch and research data up to at least year x-1 (and often, now, year x as well), typically several key estimates and forecasts are produced:

1. The total and spawning biomasses on January 1 of year x+1 and all previous years;
2. The exploitation rate (often expressed as fishing mortality) for the current year and all previous years, derived from ratios of the reported catches and estimated biomasses, and
3. An estimate of the catch for year x+1 which would correspond with the management objective through the application of a target exploitation rate and the January 1 biomass in year x+1.

From a management perspective the assessment is undertaken primarily to obtain the forecasts for January 1, year x+1, but each assessment updates estimates for the full time series. It has been known for decades that sequential population analyses converge over time (Ricker 1975), so our perception of the history of a stock becomes quite stable. However, frustratingly often, when the process is repeated the next year (during year x+1, for forecasts of January 1, year x+2 and all previous years), those estimates of the biomass and exploitation rates in recent years differ in systematic ways from the estimates of the same entities obtained in year x. This is the "retrospective pattern". It means that the management during that year has been based on false premises, and management objectives have not been achieved. Often the pattern is repeated for several successive years.

How widespread and how serious is this retrospective problem? Consider the set of groundfish assessments conducted by the International Council for the Exploration of the Sea (ICES) in the autumn of 1998 for fish stocks in the North Sea, Barents Sea, and northern shelf of the European Atlantic coast. These assessments have been chosen because of the availability of the necessary documentation to the author, and because of the fact that these assessments, for the following reasons, should be among the best family of assessments conducted by the fisheries science community:

1. Data is collected by competent national and international fisheries management agencies where there are serious efforts to manage the fisheries and to provide catch statistics;
2. The data from these fisheries are augmented by abundant survey data of high quality;
3. The biology of the species is known well;
4. ICES draws on an extremely skilled and experienced community of assessment scientists for preparing and reviewing the assessments, and
5. The time series of catches and survey data are relatively long.

To gain some consistent perspective on the course of retrospective changes over time, this paper considers the estimate of fishing mortality in year 1994, from assessments using the most current data set, but truncated in 1995, 1996, 1997, and 1998. Table 1 presents the estimates of F in 1994 over that period. For some stocks, such as saithe and sole in the North Sea, our perception of the exploitation intensity has changed very little. For other stocks, such as most of the whiting stocks, our estimates have changed greatly. It is of interest to note that although the larger changes do not appear to be random, the apparent bias is in the same direction for several successive years. The direction of this bias is not consistent, however, for all stocks. In some cases, such as North Sea plaice and Barents Sea haddock, assessments have become generally more optimistic rather than pessimistic about the state of a stock,

Table 1. Estimates of fishing mortality in 1995 for groundfish stocks in the Northeast Atlantic, if the most current catch and survey data series is truncated in 1995, 1996, and 1997. Data from ICES 1999 a, b, and c. It is not possible to estimate f analytically for Norway pout, so estimates are of Spawning Stock biomass.

Stock name (age range)	**Data series truncated in:**		
	1995	**1996**	**1997**
North Sea cod (2-4)	0.64	0.68	0.78
North Sea Haddock (2-6)	0.67	0.74	0.85
North Sea whiting (2-6)	0.47	0.58	0.73
North Sea saithe (3-8)	0.58	0.58	0.56
North Sea sole (2-8)	0.51	0.46	0.52
English Channel sole (3-8)	0.59	0.41	0.28
North Sea plaice (2-10)	0.43	0.45	0.39
Skagerrak plaice (4-8)	0.86	1.08	0.81
English Channel Plaice (2-6)	0.59	0.57	0.40
North Sea Norway pout (SSB in t)	1.6×10^5	1.7×10^5	2.2×10^5
Barents Sea cod (5-10)	0.51	0.69	0.78
Barents Sea haddock (4-7)	0.41	0.31	0.30
Celtic Sea whiting	0.88	0.77	0.62
Whiting in subarea VIa	0.92	0.81	0.79

It is not the intention of this paper to single out the ICES community. Retrospective patterns are comparably common and serious in Canadian Atlantic groundfish assessments. Because many stocks are in a state of collapse, current analytical assessments are not always available and the illustrations have to come from different years. The small sample of data detailed below shows the magnitude of the problem, particularly during the late 1980s and early 1990s, when the stocks were on the verge of collapse (Table 2, Fig 1). The overly optimistic assessments are recognised as an important contributor to the eventual collapse of many of these cod stocks (Parsons 1993, Rice in press).

Table 2. Retrospective analysis of some Canadian Atlantic cod stocks. Data from CSAS and ASAS research documents and assessment authors (see www//.dfo.mpo.gc.ca.csas). Because of changes in analytical approaches to individual stocks over the 1990s, the target year, range of years, and estimated attribute [Attr: f = fishing mortality; n = 3+ numbers (,000); r = millions of recruits at age 2] varies among stocks.

Stock	Attr.	Target Year	Years of Estimates	Value of the estimate in each year			
2J3KL	F	1989	1989-91	0.42	0.58	0.89	na
3Ps	N	1993	1994-97	38,000	52,000	82,000	62,000
3Pn4RS	N	1992	1993-96	21,000	28,000	30,000	30,000
4TVn	F	1991	1992-95	0.34	0.46	0.53	0.54
4Vn(summer)	F	1991	1992-95	0.28	0.19	0.35	0.41
4VsW	F	1992	1993-96	1.72	1.14	1.23	1.30
4X	R	1992	1994-97	17	23	28	25
5Zj,m	R	1992	1994-97	1.5	1.9	2.9	4.2

It is important to note that the preceding tables under-represent the potential magnitude of the retrospective problem. These studies were conducted using exactly the same model formulations, and merely terminating the input data series at different years. Real assessments are done annually, and in successive assessments, there are likely to be methodological differences. The analytical formulations often change at least in detail from one meeting to the next, as do the relative mathematical and interpretational weightings given to different aspects of the data and the fits between population reconstructions and data sets. Consider Barents Sea cod, supporting one of the greatest cod fisheries in the world. The management target of F_{med} (ICES in press), is generally considered sufficiently conservative, and simulations indicate this rate of exploitation is very likely to be sustainable (Gabriel 1994, Mace 1994, ICES 1997a, 1997b, 1998a). The successive assessments in 1996, 1997, and 1998 (ICES 1997c, 1998b, in press) have reduced the estimate of the January 1, 1997 SSB by over 40%, and the 1997 catch corresponding to the management target by over 50% (Table 3a). This is not an isolated case; changes to the estimates of Northern cod in 1987, from the 1989 to 1992 assessments were of comparable magnitude (Table 3b, CAFSAC 1990, 1991, 1992, 1993).

Table 3a. Estimates of Spawning Biomass (SSB x10^3 t) and target catch (x10^3 t) consistent with F_{med}, for the year 1996, from assessments of Barents Sea cod in 1996 (ICES 1997c), 1997 (ICES 1998b), and 1998 (ICES in press).

Assessment Year	SSB	Target Catch
1996	1,300	994

1997	839	514
1998	762	478

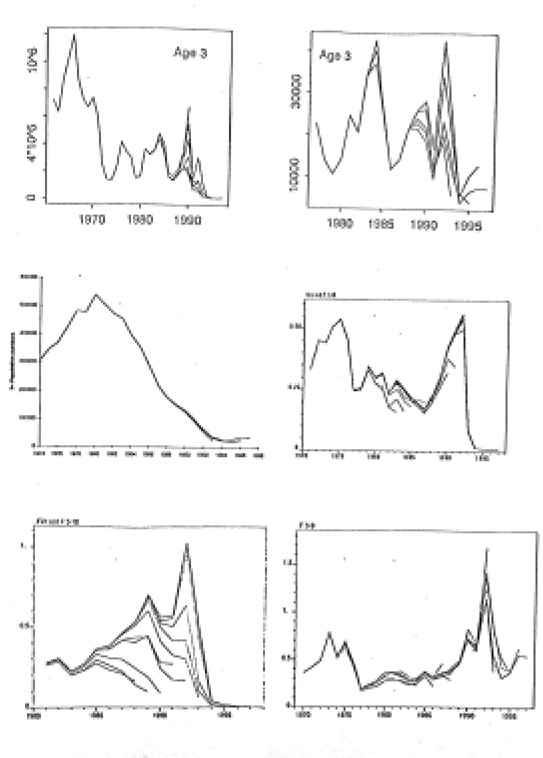

Figure 1. Illustrations of retrospective patterns from current assessments of six Canadian Atlantic cod stocks for 3+ biomass (2J3KL, 3Ps, 3Pn4RS) or f [4TVn, 4Vn (summer), 4VsW]. Except for 3Pn4RS, the retrospective analysis is not of the final formulation accepted by the peer review body, either because additional components of the stock could not be concluded in the single analytical framework (2J3KL, 3Ps), or input patterns of natural mortality over time were changed in the final runs, and retrospective analyses were not repeated with the revised formulations.

Table 3b. Estimates of 3+ biomass, SSB (x10^3 t) and f from assessments of cod on NAFO Div. 2J3KL in 1988, from assessments in 1989, 1990, 1991, and 1992 (CAFSAC 1990-1993, respectively).

Assessment Year	3+ biomass	SSB (7+)	f
1989	1,050	453	0.44
1990	840	381	0.57
1991	820	387	0.58
1992	690	110	na (high)

3 WHAT CAUSES THE RETROSPECTIVE PROBLEM?

For the past decade fisheries scientists have been searching for the causes of the retrospective problem, early warning signs that it may be present in an assessment, and methods to correct assessments for it when it is present. Although there is not yet full consensus on the details of any of these points, several generalisations are emerging (Mohn 1999). For our purposes, it is the potential causes which matter. It has been known since the 1980s that retrospective errors occur when an element or elements are systematically changing in the input data series, or there is a systematic change in the biology of stock being assessed (CAFSAC 1989). As noted earlier, the systematic aspect of such change is important as data which are just noisy simply lead to unbiased estimates with very high uncertainty.

In a fishery with a constant rate of discarding or mis-reporting the estimates of biomass and fishing mortality from an assessment based on the reported (but incorrect) catch will scale incorrectly relative to the absolute values of the stock, but trends are estimated reliably. If the management measures for the stock make the biomass trajectory stable or increasing, and the exploitation rate stable or decreasing, the stock is being sustained. This will be true even though the estimates of biomass and fishing mortality are incorrect.

For the terminal year the assessment process estimates the number and biomass of fish in each age class at the beginning of year, and decreases these numbers through the year, to account for the fish which will die from fishing activity and from natural causes. This produces the forecast population at the beginning of the succeeding year. If the rate of mis-reporting increases and the reported catch data from that year are put into the next assessment, the relative age composition shows fewer fish than were estimated for every cohort which was being discarded at the higher rate. The consequence is that the assessment estimates that the population at the start of the previous year was smaller than had been estimated last year, and, given the catch, the exploitation rate was higher than the target. This pattern continues for several years, until the assessment converges on a new relative scale. Throughout all that time management of the fishery is continually failing to meet its objectives. (If the rate of discarding or mis-reporting goes down, the effects are the reverse and the conclusion that the stock was under-estimated, and the exploitation rate over-estimated remains. This may be good for the stock, but it is often unpopular with resource users who must comply with management limits which appear to be more strict than necessary to achieve agreed management targets.)

Changes in mis-reporting or discarding rates are not the only possible cause of a retrospective pattern. Changes in biological properties such as natural mortality or growth can also contribute to the pattern. In practice, of course, it is extremely difficult to partition mortality between fishery induced and natural causes (Bax 1994, Mertz and Myers 1997). To the assessment a fish is equally dead from starvation, a predator, or unreported death in fishing gear. What the sequence of assessments demonstrates is that the age composition of the stock keeps becoming younger than estimated from the previous assessment, which in turn means there were fewer fish and they were surviving more poorly than had been estimated. (Conversely, in cases of decreasing mortality, there are more fish than thought, and they are surviving better.) It is up to the scientist to determine *what* has changed about the stock and why.

Changes to fishing practices can also contribute to retrospective and current model inaccuracies. Assessment models often use catch-per-unit-of-effort (CPUE) to calibrate relative trends and population values to some absolute scale, fixed by the absolute catches of commercial vessels. The problems with using CPUE are well known (Walters and Maguire 1996, Hilborn and Walters 1992), and in recent years, methodological alternatives have been developed (ICES 1993, 1995a, NRC 1998). These methods have their own problems, though (ICES 1995b, NRC 1998), and CPUE remains an attractive property to scale modelled populations to real ones. The use of CPUE, however, assumes that units of effort remain constant over time and does not account for changes to gears, vessel efficiency, or an increasing knowledge of the resource user on how to harvest their target stocks. All these changes alter the absolute catch per hour of fishing, per 1000 hooks, per metre of net, or by whatever catch unit is used. Such changes alter the scaling between the index and the population, resulting, for example, in an increase in efficiency falsely appearing as an increase in the stock (Walters and Maguire 1996). Again, this is not a unidirectional problem. In recent years industry has adopted many gear modifications to improve conservation aspects of harvesting. If such modifications lessen efficiency somewhat, this could change the scaling in the other direction, leading to a false suggestion that the stock is not benefiting sufficiently from the conservation measures, or that the measures are overly costly in terms of foregone catch.

Even if one is not using CPUE, changes to fishing practices can still contribute to inaccurate assessments. If a fishing gear or the prosecution of a fishery, in space or time, changes in ways which affect the age composition of the catch, or cause a different portion of the stock to be exploited, models assuming constant selectivity can go awry, sometimes badly (Casey 1996, Dealtaris and Riedel 1996, ICES 1998c). These effects again often appear as a retrospective pattern. The assessment process, in such circumstances, forecasts an age composition for the population and catch in the management year, assuming historic age selectivity for the fishery. When the catch data and the next assessment's population are reviewed, there are systematic differences in the age composition, which lead the assessors to conclude the past assessment was in error. This again continues until the several most recent years in the data series reflect catches from the new selectivity pattern.

In these two cases the absence of ancillary information about the fishery or stock underlay the inaccuracies in the assessments rather than the unreliability of the catch data. Mathematical models which reconstruct the population, or which estimate parameters of it, make specific assumptions about the biology of the species, and activities of the fishery. When natural mortality or selectivity change, or the fishery begins to exploit a different portion of the stock, these assumptions become invalid. These assumptions can be changed easily enough. The problem is to know when change has occurred, and in what way.

4 HOW DO MONITORING PROGRAMMES HELP THE ANALYTICAL ASSESSMENTS?

Monitoring fisheries will provide data on commercial catches, which are representative and reliable (as long as the monitoring programmes are designed and implemented competently). Simply by providing complete data on catches, bycatches, and discards consistently over a period of time, assessments will be able to begin with reliable data. Improvements in the quality of traditional commercial data will eliminate one source of inaccuracy in assessments; a source of inaccuracy which in simulations (where the "true" population trajectories are known, unlike the trajectories of actual fish stocks) often dominates all results, and is often a major contributor to large retrospective patterns.

More reliable data therefore, results in more accurate assessments. Whether the assessments have higher or lower variance (i.e. whether or not population estimates, and estimates of yields given target exploitation strategies, have broader or narrower confidence regions) depends on many details of the fishery and the monitoring programme. Even if the uncertainty of estimates is not changed, though, the potential for bias will be greatly reduced. As it is often the use of biased estimates which lead to particularly poor management decisions the importance of competently designed and implemented monitoring programmes is essential. As a result the traditional scientific basis provided to fisheries managers as an objective component of their decision-making will be more sound which should lead to better decisions by fisheries managers and improvements in both the sustainability of stocks and the economic viability of fisheries.

It may be a false hope that improved data immediately lead to more accurate analytical assessments, because the mathematical models themselves may be more poorly structured than envisaged. However, improved data are, by definition, a better reflection of the actual events in a fishery and the biological population being sampled. The scientific advice arising from an assessment is, in consequence, more than just the results of the mathematical computations and also contains an interpretational component. This interpretational component is very flexible, and it can change faster or slower than the actual annual computational results change

(Finlayson 1994). It is possible that as the traditional data become more and more reliable reflections of events in exploited fisheries and populations, the data alone will guide the scientific community to more accurate interpretations of model outputs. In the medium term the improved interpretations of events will prompt changes to the model formulations as well, replacing erroneous formulations with ones more consistent with the improved interpretation of reality. So, even in this completely scientific loop, monitoring programmes necessarily lead to improved scientific advice, and more reliable mathematical formations of fisheries and biological processes.

As well as providing more reliable, traditional data integrated monitoring programmes provide new kinds of data as well and allows more complete recording of fisheries activities and vessel characteristics (e.g. gears used, exact places and times fished, and vessel features). One immediate benefit of such an approach is protection against undetected changes in fishing practices affecting gear selectivities, which is another common contributor to strong retrospective patterns. Other benefits include the ability to scale effort to something more than vessel length or horsepower, and look at catch rates more finely than perhaps days fished, providing additional fishery based indices of stock status. It may be less obvious, but also true, that integrated fisheries monitoring can allow a wider range of biological attributes of the catch to be measured. This gives us an opportunity for early detection of changes in growth and mortality rates, again increasing our protection against undetected retrospective assessment errors. Further consequences of improved monitoring practices include not just better measures of traditional parameters, but accurate measures of new parameters as well. These will allow even swifter and larger improvements to model formulations, replacing coarse surrogates of fishing capacity or power with more meaningful measures.

Another important consequence of improved advice will be the opening of the scientific loop. As the scientific advice becomes more accurate, the reasons for industry to distrust it may be reduced. Input data will be recognised as more reliable and through the processes explained above, the interpretations and model formulations are likely to become more credible as well. As the assessment data and models become more credible, we can hope that the distrust between sectors is another casualty of the monitoring programmes. When rational individuals can see that the model formulations of fishing activities are based on, and fit to, accurate representations of the true activities, they should distrust the results much less. Less distrust should lead to a higher likelihood of compliance with management plans based on the results. Better compliance will feed back to further improvements in data quality and comprehensiveness. Moreover, when the scientific and management communities have confidence in the data and models, the temptation to produce conservatively biased "precautionary" results or management implementations (see discussion in ICES 1997b, 1998a) is lessened, removing another source of distrust among parties.

Continuing the stepwise evaluation of benefits, the diminishing distrust among the scientific, management, and industry sectors produces its own benefits. As the marine ecosystem and the fishery-ecosystem interactions are complex (ICES 1995b, 1998d) it is unreasonable to expect integrated fisheries monitoring programmes to provide the basis for completely reliable analytical assessments in every case. Consequently alternative hypotheses about fishery and biological processes are a major component of many assessment models, and a major source of uncertainty in results.

The effects of better data and better model formulations may allow some alternative hypotheses to be rejected, and reduce the overall uncertainty about stock status and effectiveness of management actions. A more important contribution of integrated fisheries monitoring programmes is perhaps, the fact that, through greater trust and interaction amongst and between sectors, new and better hypotheses may be incorporated into fisheries models. Knowledgeable industry members can provide highly insightful hypotheses about marine ecosystems, and about ecosystem-fishery interactions. In this instance also monitoring programmes may lead to new processes being incorporated into assessment models as well as increasing the accuracy of traditional model formulations.

5 SUMMARY

The implications of an effective integrated monitoring programme on the historical patterns observed in fisheries and assessments would be

1. More reliable data for inputs to assessments;
2. Development of better models for assessment computation. Models can be assessed and be made more complete and realistic;
3. Increased trust can be developed between scientists, managers, and industry. The greater accuracy of assessment computations, and improved model formulations can make assessment results correspond more closely with industry's experiences, increasing their confidence in the assessments. At the same time the objectivity and empiricism of the monitoring programmes means that scientists and managers have greater confidence that the information they are working with is actually what the industry is doing. Moreover, the very nature of a monitoring programme provides a forum for the sectors to work closely together, and the common toil provides opportunities to break down unhelpful stereotypes that each sector may have of others, and
4. Common objectives are required between parties. Superficially, monitoring programmes do not address objectives of scientists, managers, and fisheries. At a fundamental level, however, all parties must share broad core objectives of viable fisheries in sustained ecosystems. Problems arise when each party considers, on its own terms, whether a particular suite of measures of stock status and fisheries performance reflect viability and sustainability, and if not, what must be done to get there. It should be plausible that when all parties work with and trust common data, and models contain the processes which all parties agree are relevant and important, that there are many fewer disagreements about whether viability and sustainability are being achieved, and about the consequences of measures proposed to achieve or maintain those overall objectives.

New management approaches come with great fanfare, which fades as the promise is not delivered. Although integrated fisheries monitoring could be another such case, this is not the view of the author. Effective monitoring to obtain comprehensive and reliable data is not a new idea, and is not founded on novel theories of either ecology or fisheries. Rather, we are addressing the basics with objectivity, rigor, and common good will. That's a good foundation for a good future.

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Bycatch control through technical regulations and fisheries monitoring

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Abstract: The current Norwegian fisheries management regime has been developed since the early 1970s. With a major goal to obtain sustainability in the fishing industry, the exploitation of most commercial fish stocks are now limited by total allowable catch (TAC) regulations and minimum legal fish sizes for most important species. Additionally, the management strategy includes different approaches to minimise various types of bycatch. Adequate bycatch control is attempted through different management measures such as minimum legal fish size, temporary closure of fishing grounds and a general discard ban. To obtain the desired effects of these regulations, emphasis is put on control and enforcement at sea as well as control of the landings. The increased complexity of different regulatory measures has, however, complicated fishing operations. From the fishermen's point of view, the price of sustainability is therefore, a complicated situation on the fishing grounds, with reduced efficiency and short-term profitability. To minimise this conflict of interests, research on improved size- and species selectivity of different fishing gears has been emphasised. The work has

particularly been focused on improved selectivity of trawl gear, where the bycatch problems have been most pronounced. In addition to codend mesh regulations, the development of sorting grids in different trawl fisheries have been proven to be successful solutions to minimising bycatches of unwanted sizes and species. Sorting grids have also been developed for size grading in various purse seine fisheries. Technical solutions for improved selectivity of stationary fishing gears have also been developed, e.g. different approaches to reduce the bycatch of birds in longline fishing. Technical measures and devices for sorting fish during the capture process have limited value if this induces high mortality on the released organisms. Results from studies of by-mortality related to different bycatch reducing devices are therefore, described and discussed.

1 INTRODUCTION

The prime goal of current fisheries management systems, the majority of which have been developed during the last two decades, has been sustainability. Of particular importance in the achievement of this objective is the safeguarding of recruitment to fish stocks. Different approaches to the minimisation of bycatch of juvenile fish and other marine organisms has therefore, been a central element in the development of modern fisheries management regimes. In recent years the bycatch concept has been extended beyond juveniles of commercial species to include species that for various reasons are currently classified as unwanted bycatch.

The complexity of fisheries regulations has increased as a consequence of this development with an accompanying complexity also evident in the administration of fisheries. A great challenge in the future development of management strategies is therefore, to find cost effective ways of bycatch minimisation that at the same time maintains the highest possible efficiency in fisheries.

This paper gives a short description of the management approach used to minimise unwanted bycatches in Norwegian fisheries. To a large degree this presentation is built on a recent paper by Isaksen *et al*. (subm.).

2 THE LEGAL FRAMEWORK

In the 1970's minimum mesh size regulations were introduced in Norway's various trawl fisheries to reduce the bycatch of juvenile fish. These were set as a compromise in order to avoid large catches of juveniles of the main, target species, whilst allowing minimum legal landing sizes for other species to be achieved.

With the introduction of a new article of marine legislation (Act for Marine Fisheries) in 1983, some new principles were established. One of the most important of these stipulated that the discard of illegal bycatch was only acceptable if there was a high probability of survival. This regulation later developed into a discard ban for the principal commercial species. Another major change in the regulations was the shift from minimum legal landing size to a minimum legal size for all species caught rather than landed. Most commercial stocks, in Norwegian waters are subject to total allowable catch (TAC) () regulations, accompanied by maximum bycatch allowances either of undersized fish or legal sizes of other species. The bycatch allowance is normally set to a predetermined percentage of the legal catch. If the bycatch allowance is exceeded, it is illegal to continue fishing in the area and the vessel is obliged by law to change fishing grounds until the catch composition is in accordance with the bycatch regulations.

The enforcement of these regulations and the assurance that they are met by the fishermen, is a difficult task. Although observers could be a solution to this problem, the high diversity of vessels and fishing methods present in the Norwegian fishing fleet makes this a complicated option. This problem is exemplified in the Barents Sea cod (*Gadus morhua*) quota where approximately 30%of the quota is taken by large trawlers, while the remainder is taken by a large number of small coastal vessels using different gears (e.g. gillnets, longlines, seine nets and jigging gear). The management approach has therefore, been to monitor the major fishing grounds and temporarily close areas with large abundances of juvenile fish or protected species.

3 TEMPORAL AREA CLOSURES

With the introduction of the new legislation, a programme for monitoring fishing grounds was established. During the course of the fishing season chartered fishing vessels, with representatives from the Norwegian Directorate of Fisheries, survey the major fishing grounds. Sampling of the catch allows areas to be closed at short notice if the bycatch of juveniles exceeds preset levels. In the trawl fishery for cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), areas where the combined number of undersized fish exceeds 15% are closed and kept closed until the results of the sampling programme show an acceptably low ratio of juveniles.

The duration and area effected by closures of the fishery vary with the size composition of the commercial stocks, the relative geographical distribution of fish of different sizes and the pattern of exploitation evident in the fishery. To illustrate the dynamics of area closures, the 1998 situation is illustrated in Figures 1a-e. Figure 1a shows an integrated picture of the areas in the Barents Sea that were closed during certain periods in 1998. The first closure took place at the end of March in the groundfish trawl fishery (Fig. 1b) In June a small fraction of this area was reopened for fishing, while a new area was closed (around Bear Island), so that the total area closure was enlarged (Fig. 1c). This area closure was effective until 1 October, when the area adjacent to the mainland was opened, while the closed area around Bear Island was extended and an additional area at Svalbard was closed (Fig. 1d). In November most of the Bear Island grounds were reopened for fishing while the closed area at Svalbard was extended.

Similar temporary area closures are also practised in other fisheries (e.g. The Barents Sea shrimp fishery) where the grounds are closed if the bycatch levels of juvenile cod, haddock and Greenland halibut (*Reinhardtius hippoglossoides*) are exceeded. Similarly, the fishing grounds for saithe (*Pollachius virens*) may be closed when the bycatch of undersized fish exceeds 10% by weight in the purse seine fishery.

4 CONTROL AND ENFORCEMENT

With the experience gained from at-sea sampling, it was recognised that the control of bycatch at the point of landing was not an appropriate measure in the effective enforcement of the new fisheries regulation. A considerable increase in the control of fishing activities at the point of capture was therefore, a natural consequence of the requirements of the new management regime. The responsibility for the control and enforcement of bycatch and other fisheries regulations is borne by the Norwegian Coast Guard, which constitutes a separate branch of the Norwegian naval forces. The Coast Guard has been significantly strengthened during recent years and has also been specially adapted for effective control and enforcement of fisheries regulations.

Coast Guard inspections which are conducted during actual fishing operations are comprehensive. The inspectors check that the accumulated catch is in accordance with the vessel's logbook, inspect the gear (e.g. for legal mesh size or other regulated gear parameters) and take a representative sample from the most recent catch. If irregularities are detected the enforcement action may vary from a warning to the imposition of heavy penalties in accordance with the severity of the irregularity. A checkpoint system is also established for the inspection of the offshore fleet, and in particular those vessels that land catches in foreign ports and thus are not subject to landing control in Norway. At the end of a trip the vessel is obliged to report to the Coast Guard when they expect to be at a check point position along their main course to the landing site. The Coast Guard may then decide to make an inspection of the fishing vessel at the checkpoint. The compliance advantage of this system is that fishing vessels must always be prepared for an inspection whether one is actually conducted or not. In addition to the at sea duties of the Coast

Guard the monitoring and control of catches at the point of landing is conducted by inspectors from the Directorate of Fisheries.

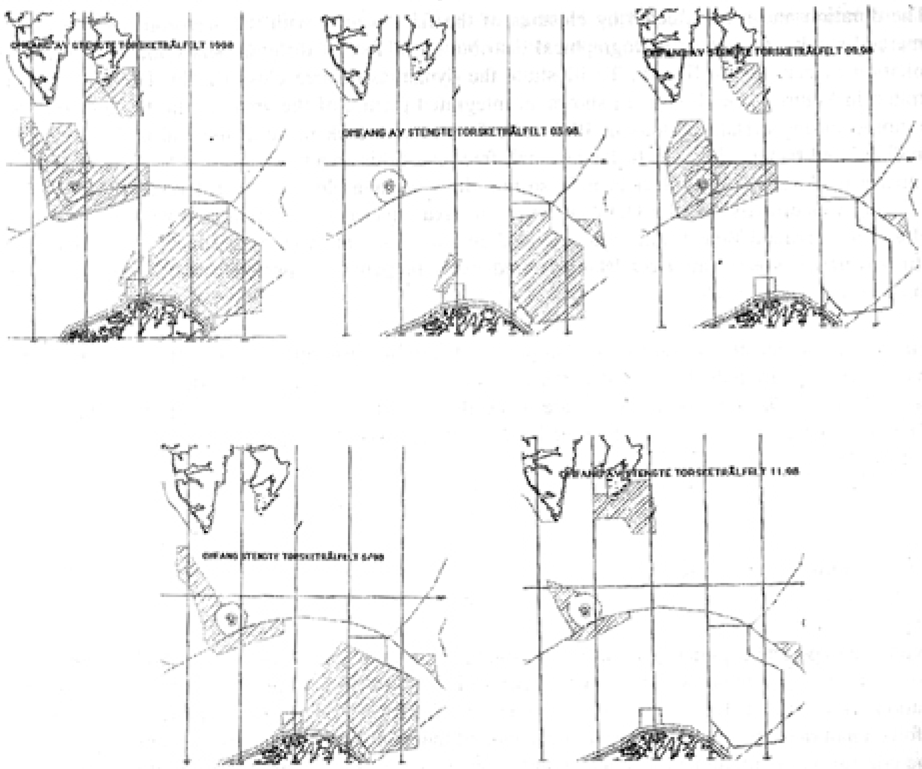

Figure 1. (Clockwise) a) Temporary closed areas for demersal fish trawling in the Barents Sea in 1998, **b)** Areas closed for demersal fish trawling in the Barents Sea, from 24 March 1998, **c)** Areas closed for demersal fish trawling in the Barents Sea, from June 1998, **d)** Areas closed for demersal fish trawling in the Barents Sea, from 1 October 1998, **e)** Areas closed for demersal fish trawling in the Barents Sea, from November 1998. (By J. P. Hansen, Norwegian Directorate of Fisheries).

5 TECHNICAL SOLUTIONS AND REGULATIONS

To make the increasingly complex bycatch regulations less cumbersome for fishermen, research on selectivity devices that reduce bycatch in fishing gears has received priority. As the major bycatch problems have been related to trawl gear and shrimp trawling in particular, the focus was initially directed on the bycatch problem in the shrimp fishery. After several unsuccessful trials with different net sorting panels to separate shrimp and fish, an adequate solution was found using a rigid (metal) sorting device (Isaksen *et al*. 1992). This has become known as the "Nordmøre grid", named after the home region of a local fisherman that invented the principle initially, to sort out unwanted jellyfish bycatch in the shrimp trawl fishery. The grid was subsequently developed and improved and acceptable results were obtained for sorting out fish with moderate losses of shrimp (Fig. 2). Organisms that enter the trawl are guided by a funnel to the lower (front) end of the back sloping metal grid. Any fish or other organisms that are too big to go through the slots between the bars of the grid slide upwards along the grid and are released through a hole in the trawl at the top end of the grid. Conversely, most of the shrimp pass through the slots between the bars of the grid and pass through to the cod end. This sorting device was made mandatory for the coastal shrimp trawler fleet in 1990 and for the offshore fleet in the Barents Sea in 1991. In addition to cleaner catches, improved catch quality and correspondingly less sorting, the fishermen benefited from the fact that they could now operate for longer periods in areas that would otherwise have been closed due to excessive bycatches of juvenile fish. In the North Sea shrimp fishery the *Nordmøre grid* is not mandatory, but it is used voluntarily by many fishermen often with a large mesh bag over the escape hole to save bycatch of legal size fish. However, even if this device is a significant improvement on the selectivity of shrimp trawls, the complete solution is still being sought because existing grids do not sort out the very smallest fish nor the undersized shrimp.

The development of size sorting devices in groundfish trawls in order to reduce the bycatch of undersized fish was achieved through the development of another type of grid, termed the *Sort-X* system (Larsen & Isaksen 1993) (Fig. 3). This system is essentially a reversed shrimp grid. As fish travel back through the trawl they make contact with the grid with large fish forced backwards and downwards along the sloping grid to the cod end. Fish that are small enough pass through the slots in the grid and escape from the trawl through an open panel in the top surface of the net. From 1997 grid-sorting devices were made mandatory in all Barents Sea groundfish trawl fisheries. In Norwegian trawls the Sort-X system is currently in use and a simpler system (Sort-V) is used in Russian trawls (see Fig. 3). The Sort-V system which is easier to handle and less expensive to construct has now been successfully adapted to Norwegian trawls and will most probably be legalised for use in the Norwegian fishery in the near future.

Recent trials with sorting grids in other trawl fisheries have also recorded promising results. These have been particularly encouraging in the size selection of mackerel (*Scomber scomber*) by the pelagic trawling fleet and in the separation of cod and haddock in the North sea trawl fishery for Norway pout (*Trisopterus esmarkii)* and blue whiting (*Micromesistius poutassou*) (Kvalsvik *et al*. 1998, Huse *et al*. 1998).

In mixed species fisheries, fishermen often experience bycatch problems when legally sized fish of a filled quota are taken. Research on methods for species selective devices in groundfish trawls has therefore, been the focus of recent research and a promising solution for the separation of cod from saithe and haddock has been developed (Fig. 4). Behavioural observation of the main commercial species indicated that where cod tended to swim downwards, saithe, haddock and other species swam upwards when encountering trawl gear. Based on these observations a selection device was developed which divided the trawl into an upper and lower part using a horizontal, longitudinal panel. Field trials gave very promising results with the majority of the cod captured in the lower cod end and the majority of the haddock and saithe taken in the upper cod end. This solution could allow fishermen an opportunity to continue fishing a cod quota in a mixed fishery even if the haddock quota is reached by letting the haddock escape through an open upper cod end (Engås *et al.* 1998).

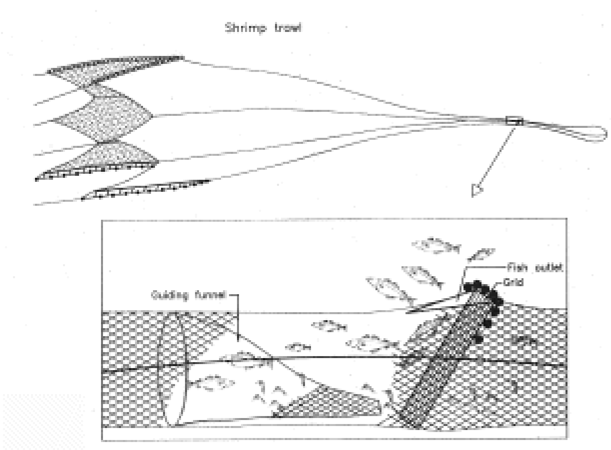

Figure 2. The *Nordmøre grid*, sorting grid for shrimp trawls. (From Isaksen *et al*. 1992).

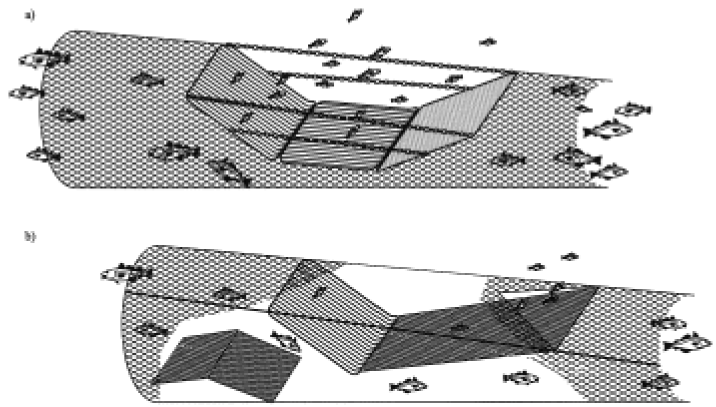

Figure 3. Size sorting grids for groundfish ; a) *Sort-X* (Larsen and Isaksen 1993), b) *Sort-V* (Lisovsky *et al*. 1996).

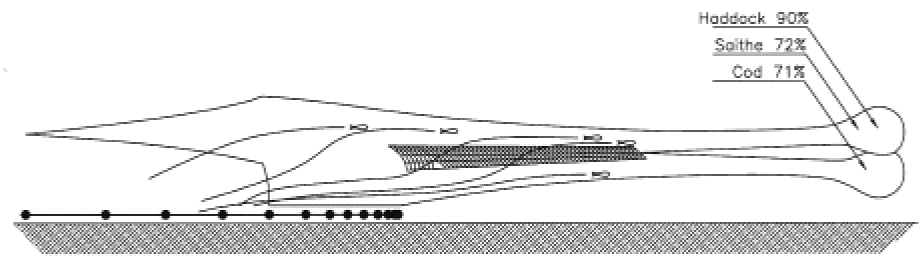

Figure 4. Groundfish trawl with horizontal panel for species separation (Engås *et al*. 1998).

Grids have also been tried in seine nets to select and separate fish by size. Although the results have been promising, the handling of grids with this gear has been adversely cumbersome. The use of square mesh cod ends has, however, significantly improved selectivity in the seine net fishery for cod and haddock, and is now being used on a voluntarily basis by many fishermen (Fig. 5). Grids have also been tried to sort fish by size in different purse seine fisheries and good results have been obtained, particularly with saithe and mackerel (Fig. 6).

A different bycatch problem that has received the focus of research attention in recent years has been the capture of seabirds by longline gear. During the setting of longlines, seabirds are attracted to the baited hooks that are accessible in the setting zone directly behind the vessel. Different solutions have been suggested and encouraging results have been obtained using either a setting funnel that guides the line below the diving depth of the scavenging birds or a bird scaring device consisting of a line with vertically hanging streamers that is trailed above the critical zone behind the vessel (Bjordal and Løkkeborg 1996). Recent experiments have shown that the seabird scaring device seems to be a superior solution to the problem with a significant reduction in the seabird bycatch and improved catch rates of the target fish species recorded when this device is deployed successfully (Løkkeborg, 1998).

In longline fishing it has been demonstrated that the choice of bait can have clear species-selective effects which can be utilised to minimise unwanted bycatch of certain species. An example is the use of a recently developed restructured bait in the mixed fishery for cod and haddock. Compared with traditional bait, the new bait catches 2-3 times more haddock, but it gives reduced catches of cod. In situations with restricted cod quotas and more liberal haddock quotas, longline fishermen have used the new bait to minimise the catch of cod. The fishermen have, therefore, been able to prolong the fishing period in this mixed fishery which would otherwise have been closed once the cod quota had been taken.

6 SURVIVAL AFTER ESCAPEMENT FROM FISHING GEARS

Reduced bycatches have been achieved by the introduction of selective measures in several fisheries. However, the introduction of methods for improved gear selectivity and the corresponding reduction of unwanted bycatch makes little sense if the released organisms suffer high mortality caused by encountering the gear. The development of methods for reducing bycatches should therefore, be accompanied with studies on the survival rates of the released organisms. Survival of fish after escapement from fishing gears has been investigated for several species (Chopin and Arimoto 1995). In general, the results show that demersal fishes (e.g. gadoids; cod, haddock and saithe) have high survival rates after escapement, while some pelagic fishes (e.g. clupeids; herring) show high mortality after encountering the gear. Survival studies on mackerel have so far not given conclusive results, and consequently the implementation of sorting grids (e.g. in mackerel trawls) has not yet been recommended.

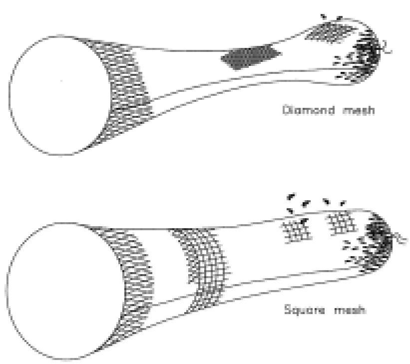

Figure 5. Seine net. Cod-ends with diamond (top) and square (bottom) meshes. (Isaksen *et al.* 1997).

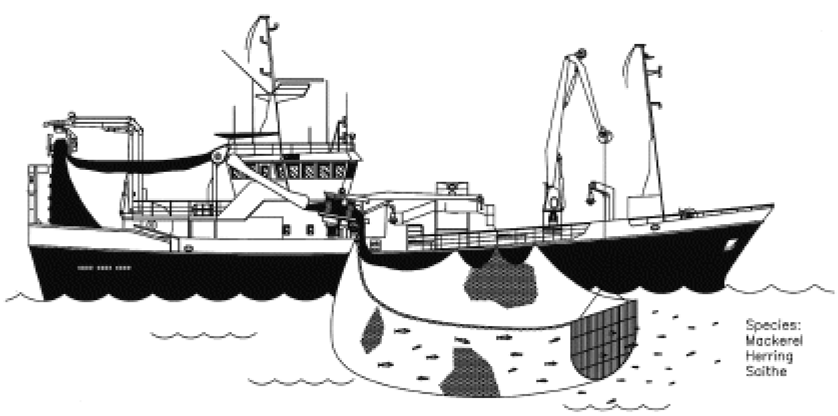

Figure 6. Size sorting grid in a purse seine.

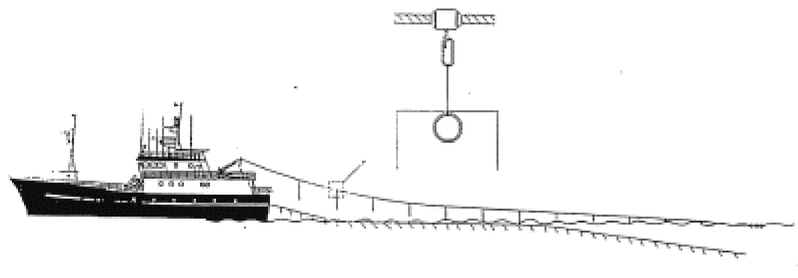

Figure 7. Scaring device for the avoidance of seabird bycatch in longlining. (Bjordal and Løkkeborg 1996).

7 DISCUSSION

Fisheries management systems are still at an early stage in the development of integrated systems for fisheries monitoring and bycatch control. To achieve adequate and cost-effective solutions in this area, further development of different approaches for bycatch reduction is needed as well as a rational integration of different selective, fishing methods. Future systems for fisheries monitoring and bycatch control will therefore, be likely to include such elements as satellite tracking of fishing vessels, closed areas, catch and landing feedback control of fisheries, onboard observers and further development of selective fishing methods.

A further challenge for fisheries research and management is the documentation and evaluation of the relative effects of bycatches and the corresponding risks to commercial and non-commercial species), and to the marine ecosystem. A holistic approach to the management of marine ecosystems should therefore, include management objectives and precautionary reference points, not only for the target species in the fisheries, but also for bycatch organisms.

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The role of fisheries monitoring programmes in identifying and reducing problematic bycatches

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Abstract: The first pre-requisite for any attempt to reduce unwanted bycatches in fisheries is accurate information on the species, quantities, sizes, locations and timing of such bycatches. Such information not only facilitates the identification of any spatial and temporal closures to fishing designed to reduce bycatches, but also allows fishing gear technologists to develop modifications that reduce bycatches whilst maintaining catches of the targeted species. There are several methods available to quantify bycatches and discards (e.g. questionnaires, interviews, logbooks, samples from fishers, data from research vessels), but it is well-accepted that the most accurate way to estimate bycatches is by using onboard observers. Observer programmes involve having fishery-independent scientists or observers gathering data during the course of normal fishing operations. If the survey design, sampling frequency and extent of the observer programme is adequate, the data gathered can be used to estimate species- and size-specific bycatches by the whole fishery across the spatial and temporal scales required for subsequent bycatch reduction programmes.

1 INTRODUCTION

The FAO Technical Consultation on Reduction of Wastage in Fisheries held in Tokyo, Japan in 1996 (FAO, 1996) recognised that pre-requisite to the reduction of problematic bycatches and discarding throughout the world's fisheries was the accurate quantification of such bycatches. Whilst the meeting noted that there were many programmes throughout the world that monitored bycatches, it was also agreed that such programmes varied considerably in their accuracy, data quality, coverage, utility and analytical value. It was therefore recommended that an international conference be held as a means for integrating many of these disparate expertises and experiences and so improve standards of monitoring fisheries and, in particular, their bycatches. This paper introduces the various methods commonly used to identify, quantify and monitor bycatches before providing an Australian example of the successful application of the most commonly used technique - observer programmes.

Fisheries bycatch has become one of the most important fisheries issues of the 1990s (Tillman 1993, Alverson et al. 1994, Kennelly 1995). Declining fish stocks in many of the world's fisheries in recent years have led to commercial and recreational fishers, conservationists, environmentalists, politicians, fisheries managers and scientists all identifying bycatch as a key problem and calling for ways to reduce it. Virtually all commercial and recreational fisheries in the world have bycatch associated with them but some methods are recognised as having more unwanted bycatch than others (e.g. bycatch of dolphins in tuna purse-seine fisheries, the bycatch of turtles in tropical shrimp trawls and, in more recent years, the bycatch of large numbers of juvenile fish in prawn and fish trawls).

Solutions to bycatch problems can be categorised as involving either spatial and/or temporal closures to fishing (e.g. closing areas to trawling to avoid the bycatch of halibut, red king crabs and Tanner crabs in the Eastern Bering Sea (Gauvin et al. 1995)) or modifying fishing gears and practices so that fisheries avoid taking unwanted species (e.g. Nordmore grids and square mesh panels releasing small fish from prawn trawls (Isaksen et al. 1992, Broadhurst and Kennelly 1997), the Medina panel and the "backdown" manoeuvre releasing dolphins from tuna purse-seines (Medina 1994). However, before closures can be identified or new gears developed to ameliorate bycatches, detailed and extensive information must be available on spatial and temporal variations in the identities, quantities and sizes of the problematic bycatches that one is trying to reduce. This identification and quantification stage is not a simple exercise because discarding of unwanted and problematic bycatches happens at sea, in isolation from ports of landing and therefore, significantly different from the usual techniques used by fisheries managers and scientists to monitor fisheries. Despite these difficulties, several methods have been used successfully to identify and quantify bycatches and these can be separated into three categories; fishery-dependent surveys, fishery-independent surveys and, most importantly, observer programmes (which can be considered as combinations of the first two categories) (Table 1).

Table 1.Summary of the main characteristics of the 3 main ways used to identify and quantify bycatches and discards.

Category	Examples	Costs to managing agency	Inconvenience to industry	Precision	Accuracy	Reliability	Representation of normal fishing
Fishery-dependent surveys	Interviews with fishers, logbooks, samples collected by fishers.	Low	High	Low	Low	Low	High
Fishery-independent surveys	Data from research vessels and chartered commercial vessels.	High	None	High	High	High	Low
Observer programmes	Fishery-independent observers on normal fishing operations	Intermediate	Intermediate	High	High	High	High

2 FISHERY DEPENDENT SURVEYS

Typical methods used in fishery-dependent surveys to quantify bycatches include interviews with fishers, logbook completion and sample collection by fishers, for processing by scientific or management agencies (e.g. Jermyn and Robb 1981, Hudon 1990). The main advantages of these surveys is that they are very cheap for scientific and management agencies to execute because fishers do most of the data-gathering. However, the trade-off is that there may be substantial inconvenience to fishers in terms of onboard and/or dockside processing. The main disadvantage of these methods of data collection, however, is that the data gathered can be inaccurate and biased particularly when the bycatches to be censused by fishers are the subject of controversial issues.

3 FISHERY INDEPENDENT SURVEYS

Fishery independent surveys include those done by research vessels or chartered commercial fishing vessels where scientists identify and quantify bycatches as they attempt to mimic commercial fishing operations (Gutherz and Pellegrin 1988, Gray *et al.* 1990, Watson *et al*. 1990). The data gathered in such surveys are usually very precise recordings of bycatches because they are conducted by trained scientists in ideal sampling conditions and generally involve no inconvenience to fishers. However, these surveys are generally expensive due to the large costs associated with running research vessels and/or chartering commercial vessels. The main problem with such methods of data collection, however, is that the data can be argued to be non-representative of normal commercial fishing operations. This criticism is levelled because the data may not reflect the myriad strategies and associated biases introduced during commercial operations as skippers and crews try to maximise their catch and/or profit. Factors such as the price of target species, weather conditions, gear characteristics, personal preferences and the day-to-day circumstances of skippers and crew can all influence fishers during their "normal" fishing operations and are usually ignored in fishery-independent surveys of bycatches.

4 OBSERVER PROGRAMMES

It is generally accepted that the most accurate, reliable and representative way to monitor bycatches is through onboard observer programmes (Saila 1983, Howell and Langan 1987, Alverson *et al*. 1994, Kennelly 1995). Observer programmes can be viewed as a combination of fishery-dependent and fishery-independent surveys because they involve fishery-independent observers (generally with a scientific background) working on fishing vessels during normal operations, recording data on catches, bycatches and fishing operations *in situ*. One of the characteristics of these programmes is that they are relatively inexpensive for scientific and management agencies to operate because the costs incurred are significantly less than those involved in running large research vessels. As a trade-off to these cost-savings, however, there is some inconvenience to fishers because observer programmes involve an extra person (or persons) onboard the vessel occupying deck space and conducting activities that are outside normal fishing practices (e.g. measuring, weighing and recording information on many species). Whilst the data from these programmes are usually considered to be very accurate, precise and reliable, their most important feature is that they are considered to be representative of normal fishing activities and therefore of considerable importance to fisheries scientists and managers. It is important to note, however, that confidence in the representative nature of the data collected by observer programmes requires the assumption that fishers behave normally with an observer onboard. In most fisheries this is probably the case, but in situations where fishers believe that they may gain some longer-term advantage (in catch or profit) by behaving atypically in the presence of observers, this assumption can be violated. This situation can occur, for example, when fishers consider that it is in their best, long-term interest to forgo short-term profit and/or catch volume by fishing in an abnormal fashion so that an observer does not record bycatches of some controversial species. In such situations, however, it is far easier, and less disadvantageous in the short-term for such fishers to simply refuse to take an observer in instances where the observer programme is voluntary. However, in cases where this problem arises (e.g. in involuntary observer programmes), it is important that such instances are identified to avoid biases being introduced into databases.

5 DESIGNING OBSERVER PROGRAMMES

Because observer programmes usually can not monitor 100% of all fishing trips and catches in a fishery, the allocation of observer effort requires some form of sub-sampling regime. When designing such programmes, one needs to apply accepted survey design standards to ensure that all samples and sub-samples are appropriately randomised, stratified across all spatial and temporal scales and sufficiently replicated for reasonable levels of precision. By incorporating these design factors into observer surveys of bycatches, the extrapolation of results from relatively small numbers of observed trips to statistically reliable bycatch estimates of whole fisheries becomes straightforward. A number of these design factors are illustrated in the following case study.

6 BYCATCH QUANTIFICATION IN THE PRAWN-TRAWL FISHERIES OF NEW SOUTH WALES, AUSTRALIA : A CASE STUDY:

In New South Wales (NSW), Australia, estuarine and oceanic prawn fisheries mainly target eastern king prawns and eastern school prawns. These fisheries have experienced significant bycatch problems for many years, going as far back as the late 19th century (Dannevig 1904), which have received recent review (Kennelly 1995). In the late 1980's these concerns reached a maximum and resulted in threats to close certain prawn-trawl fisheries in order to stop the bycatch and discarding of juvenile fish. To address this problem, researchers firstly identified and quantified the relevant issues using scientific observer programmes, and then reduced the problems that were so identified through modifications to trawling gears.

Identifying and quantifying bycatches of juvenile fish in NSW's prawn trawl fisheries involved the determination of spatial and temporal variabilities in bycatches at a species-specific level. This could only be accomplished by scientific observers recording such information onboard commercial vessels during normal fishing operations. Such data could not be collected from information on landings, nor could fishers be relied upon to provide accurate data on discards and it was argued, in fact, that it was in the fishers' best interests not to provide such information. Therefore, scientific observers gathered the required data by working alongside fishers on their own vessels and collecting the data *in situ* by sorting, identifying, measuring, counting and weighing catches and bycatches from each tow. These observer programmes were active from 1989 to 1992 with observers placed on replicated, randomly selected vessels conducting typical fishing trips in several estuaries, from several oceanic ports throughout NSW. Due to financial constraints, only a small fraction (< 5%) of all fishing trips carried out during this time could be sampled by observers, meaning that the allocation of observer effort had to adhere to a carefully prepared sub-sampling regime.

Firstly, the 4 oceanic ports and 4 estuaries examined, which encompassed most of the prawn-trawl effort in NSW, formed the basic spatial units to be sampled. Secondly, because prawn trawlers in these places reported their fishing effort as the numbers of days (or nights) fished per month, the minimal temporal scale to be sampled was defined as months within each season during the 3-year period of the project. Because of the number of ports/estuaries to be sampled in each month, and the limited number of observer days available, only 4 replicate trips were allocated to each port/estuary per month on vessels selected at random from the various fleets. By stratifying the survey design across each port/estuary, in each month, season and year of the project, all spatial and temporal scales that were appropriate to the oceanic and estuarine prawn-trawl fisheries of NSW were sampled. This allowed the straightforward calculation of bycatch rates (expressed as average weights and numbers of by-caught species per day fished) with low levels of precision (Liggins and Kennelly 1996, Liggins *et al*. 1996, Kennelly *et al*., 1998). The subsequent incorporation of fishers' reports of the total numbers of days/nights fished per month per port/estuary, allowed estimates of total bycatches per fishery (with associated levels of precision) to be extrapolated. Without this stratified and randomised design across all relevant spatial and temporal scales, these total estimates of bycatches per fishery (which are the main interest to managers and scientists wishing to reduce problematic bycatches) would have been more difficult, if not impossible, to determine.

The data from these observer programmes provided very detailed information on the bycatches of many species of juvenile fish by the various prawn-trawl fleets (Liggins and Kennelly 1996, Liggins *et al.* 1996, Kennelly *et al.* 1998). For example, in the Clarence River estuarine fishery in the 1991/92 season, it was estimated that in catching 270 t of prawns, this fishery discarded 123 t of bycatch, including approx. 0.8 million individuals of the recreationally important yellowfin bream (*Acanthopagrus australis)*. Meanwhile, in the oceanic fishery offshore from four of the main ports in 1990 to 1992, 1,579 t of prawns were estimated to have been caught with an estimated 16,435 t of bycatch. Of this bycatch, an estimated 2,952 t was landed for sale as "by-product" (including various species of slipper lobsters, squid, octopus and large fish) while the rest (some 13,458 t) was discarded (including approx. 13 million red spot whiting *(Sillago flindersi)*).

Detailed information on bycatches such as these were given to prawn-trawl fishers throughout NSW in the form of reports on each fishery and discussed in various meetings. These meetings eventually led to the identification of the key bycatch problems in some detail (in terms of species, locations and times) and so permitted workers to focus on solutions involving a variety of gear modifications (including the Nordmore Grid and a new type of composite square-mesh panel) that reduced unwanted bycatches whilst maintaining catches of prawns (Broadhurst and Kennelly 1994, 1995, 1996a, 1996b, 1997, Broadhurst *et al.* 1996a, 1996b, 1997, Kennelly and Broadhurst 1996). These solutions have since become law in these fisheries and have resulted in a significant reduction in the prawn-trawl bycatch controversy in NSW.

7 CONCLUSIONS

Solutions to bycatch problems, whether they involve spatial and temporal closures or modified gears and fishing practices, are often simply implemented into a fishery without firstly identifying and quantifying the species-specific, and size-specific, nature of the particular problems. Without this preliminary information, which is ideally obtained through scientifically conducted observer programmes, the implementation of such solutions which may have been developed for use in some other fishery, can lead to substantial conflict with the industry without really solving the initial problem. Different fisheries in the world usually have very different bycatch problems, and it is only appropriate to start developing fishery-specific solutions after determining the species-specific and size-specific nature of the problem(s) in the particular fishery of interest. While there are several ways to estimate bycatches, including fishery-dependent and fishery-independent surveys, by far the most accurate, reliable and representative method is to use properly designed observer programmes. However, to maximise their utility, such programmes must incorporate appropriate levels of replication, randomisation and stratification across all spatial and temporal scales involved in the particular fishery's bycatch issue.

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Fisheries monitoring: A proposed Canadian model for an "Integrated conservation and management system" (ICAMS)

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Abstract: The ICAMS approach is a logical business approach to the orderly management of a highly regulated industry. The focus is on industry monitoring and verification of the processes that are used to ensure the sustainability of the fishery resources. The regulatory agency retains legislative control therefore, ensuring compliance.

1 INTRODUCTION

Various approaches have been used in the past to monitor and ensure compliance with fisheries management measures. Many of these approaches have not achieved their full potential. In the Canadian context, the rapid development of the fishing industry and the equally rapid evolution of the fisheries management process have resulted in a significant lag in the implementation of new strategies and approaches to fisheries monitoring. Consequently, there has been a tendency to remain with the traditional reactive enforcement tools, i.e. air, sea, and land patrols and observers both at-sea and dockside.

The proliferation of individual management plans, micro management and fiscal constraint requires that a new approach be considered to determine conservation and management priorities within "Integrated Fish Management Plans" and that new approaches to monitoring compliance be developed.

The Integrated Conservation and Management System (ICAMS) introduces two new approaches to the issue of fisheries monitoring. Firstly, that risk assessment, threat analysis and critical control point principles be used to determine conservation and management priorities and assign enforcement resources to fisheries and secondly, that the devolution, where appropriate, of the fisheries monitoring and verification functions be effected to the fishing industry. The Canadian Department of Fisheries and Oceans (DFO) is considering both approaches as the next logical step towards achieving compliance with fisheries management measures.

1.1 Background

Since the extension of jurisdiction in 1976, the Canadian model for fisheries management has evolved extensively. In general terms the Canadian fishing industry has evolved from an open access fishery to one of limited entry which is managed on the bases of quasi-property rights i.e. individual quotas. The evolution of the fisheries management philosophy has also resulted in an increasingly complex management regime that places a greater emphasis on the social and economic aspects of fisheries management.

The evolution of the management process leading to the introduction of the Integrated Conservation and Management System (ICMS) approach began with the extension of jurisdictions in 1976.

1.2 Extension of jurisdiction

Prior to 1977, the Canadian fishing industry was primarily dependent on a small number of fisheries, which included groundfish species (cod, halibut, haddock, pollock, and flounders) the five species of pacific salmon, lobster and herring.

The fisheries, at that time, were primarily open access and competitive with little, if any emphasis on the allocation of available resources between stakeholders. Resource conservation was achieved through the use of seasonal closures, restrictions on fish size and sex and gear restrictions, e.g. mesh size limitations etc. Generally, conservation of the fishery resources was a relatively simple process that focused on the biological harvest restrictions required to ensure maximum sustainable yield. This resource conservation approach to the regulation of the resource in combination with the competitive nature of the fishing industry did not require the use of the complex regulatory and consultative processes now required to achieve social and economic objectives. At the same time, the potential collapse of major fisheries, such as the Atlantic cod fishery was not foreseen as a possibility since with the extension of jurisdiction, Canada had taken control of the management process for most stocks.

The fisheries monitoring, control and surveillance programmes of the 1970's were designed to meet the requirements of this less complex management regime and enforcement programmes prior to the extension of jurisdiction were essentially reactive. As the focus on biological regulations and the competitive nature of the fisheries did not require highly sophisticated nor complex enforcement strategies to meet the challenges or requirements of the management regime, enforcement programmes were surveillance and patrol oriented, and designed to apprehend individuals who were in violation of regulations.

Concurrent with the extension of jurisdiction came the introduction of two new economically based, fisheries management processes; firstly, resource access or limited entry licensing and secondly, resource allocation, the process of distributing the available resource amongst competing users. Essentially, the public policy direction of the government of Canada had shifted from one of strictly biological resource conservation to one, which also emphasised the maximisation of the economic rent that was available from the harvest of fisheries resources. Essentially, the fisheries management emphasis shifted from strictly biological management to one that was also directed towards the more complex human and quasi-property aspects of fisheries management.

Complimentary with the new economic philosophy of fisheries management, the DFO undertook a vigorous programme of fisheries development. There were two principle aspects of the development programme; firstly, to improve fishing gears and technologies in order to make established fisheries more efficient and effective and secondly, to develop opportunities to harvest under-utilised or non-utilised species as a means of optimising employment opportunities in coastal communities. The development thrust was consistent with the newly evolving fisheries management regime, which was focused on the social and economic aspects of the management process.

The result of the extension of jurisdiction along with the introduction of economic management and the implementation of the fisheries development programme was, ultimately the creation of a fleet of larger, faster and more technologically sophisticated vessels which radically increased the overall fishing capacity of the Canadian industry. Shortly after the extension of jurisdiction, it was recognised that many important stocks had not achieved the sustainable yields which had been projected, resulting in significant overcapacity in the harvesting sector. The management regime was now required to focus on the issues related to over capacity and in consequence the resource access and allocation processes became more complex as did the supporting management and regulatory regimes.

The management strategies introduced to address overcapacity in the harvesting sector involved the introduction of new resource allocation processes, including, enterprise allocation or individual quotas, trip limits, bycatch restrictions and increased minimum fish sizes. The march towards micro-management of the fishing industry was underway and with each passing year the management planning process became increasingly complex. Driven by industry demands, the process became further complicated by the decline of many Atlantic groundfish stocks and in particular the collapse of the northern cod stock off Newfoundland and Labrador and the decline in several important Pacific salmon stocks.

During the period of rapid industry expansion and increasing management complexity, the approaches and mechanisms for monitoring, control and surveillance of fisheries did not keep pace. The focus of the DFO was to work with the industry in an attempt to deal with the over capacity issue and in many cases the management measures which were imposed were not supported by effective monitoring programmes. It should be noted, that during the 1980's and early 1990's the fisheries monitoring, control and surveillance programme continued to be focused on the reactive or traditional aspects of fisheries enforcement i.e. air, sea and land patrols, with a high priority assigned to the monitoring of foreign fishing vessels operating in proximity to Canadian fishery waters.

1.3 Integrated fish management plans

In 1993 the DFO was required, as part of overall government fiscal constraints, to significantly reduce its operating budget. This requirement was achieved through a programme review requiring each departmental sector to analyse all elements of their programme and to make recommendations for improved programme delivery, identifying programme reductions or element eliminations, and the potential cost saving associated with the improved delivery of each element.

For the fisheries management sector the programme review exercise resulted in several new strategic initiatives, which were designed to improve the fisheries management process. These included;

1. Recognition that the primary objective for the conservation of fishery resources be that of sustainable utilisation by Canadians;
2. The establishment of a partnering initiative to foster a more innovative and self reliant fishing industry;
3. The establishment of an Integrated Fisheries Management Planning (IFMP) process with all DFO sectors and clients, including fish harvesters, providing input to the development of management plans, and
4. The development and implementation of the conservation and protection (enforcement) programme renewal strategy.

The DFO modified its approach to fisheries management planning with the introduction of the Integrated Fishery Management Planning (IFMP) process. The objective of the IFMP was to fully integrate all contributors to the fisheries management planning process, both government and industry, into a more cohesive, effective and timely process.

IFMPs were implemented to ensure that all activities of the department related to the conservation and management of the fishery resource were described and addressed in the annual management plan for particular species. This planning process includes scientific, fish management, surveillance, enforcement, aboriginal and international considerations. The process was designed to identify and describe; the conservation and management issues and concerns in the fishery; the required conservation and management measures and supporting regulatory infrastructure; the surveillance and enforcement resources required to implement the plan and, the roles and responsibilities of the fishing industry in achieving the conservation and resource allocation objectives of the plan.

The other major initiative, resulting from programme review, was the establishment of partnerships or contractual arrangements with sectors of the fishing industry. This initiative was not only introduced to foster the development of a more self reliant fishing industry but was also considered as an means of sharing the costs of science, management and enforcement activities with the industry. It was anticipated that the industry would participate in funding those management activities that were of direct benefit to them.

The IFMP and the partnering initiatives were significant steps in moving toward the new paradigm in fisheries management. Both initiatives were implemented to ensure that the department and the industry would focus on; the highest priority fishery conservation and management concerns in that fishery, the costs associated with monitoring the proposed management measures and the practicality, enforceability and affordability of the various conservation and management measures.

1.4 Current challenge

Fisheries management in Canada, as in other countries, is continuing to become increasingly complex primarily in response to industry demands for more complex methods of allocating or distributing the resource amongst the users. A significant imbalance has developed between the capacity of the fishing fleets and the capability of the resource to support it. This imbalance is primarily, the result of the improved technological capability of the fishing fleets at a time when additional resources are not available. Excessive fishing capacity in many sectors of the fishing industry has been a significant factor in the trend toward increasing complexity and micro-management of Canadian fisheries.

The increasing complexity of the management regime has also resulted in the expansion of workload, particularly for those organisations with responsibilities for fisheries monitoring and enforcement activities. This situation is further compounded by fiscal constraint measures that many governments have been required to impose. As a result government agencies with fisheries monitoring responsibilities have experienced significant reductions in resources relative to their workloads.

Increased financial and human resources for traditional fisheries monitoring, control and surveillance is not the answer to address the trend toward increased management complexity. What is required is a new process to carry out the development of fishery management plans and the implementation of fishery monitoring programmes.

2 INTEGRATED CONSERVATION AND MANAGEMENT SYSTEM

2.1 Application of risk management

The introduction of a risk based approach to the monitoring of fishing plans, within the IFMP process, is seen as the next logical step in the evolution of the fisheries management process. The risk management approach can improve the identification of the most critical conservation and management measures, improve communications with the fishing industry, and focus available resources toward those measures which are most critical to the achievement of management objectives.

The "Integrated Conservation and Management System" (ICAMS) approach emphasises the application of defined principles rather than guidelines for the development of IFMPs. These principles are consistent with the current structure of the IFMP. The basic difference is that the adoption of the ICAMS principles requires that a more disciplined and rigorous approach is applied throughout the planning and implementation processes to help direct compliance efforts. The approach requires that both the DFO and stakeholders clearly identify and articulate the risks and potential threats to the conservation of the resource and management of the fisheries. The principles also require that critical limits be established and critical control points identified, so that actions can be taken to eliminate or minimise these threats.

The principles outlined in the ICAMS approach require that consultative and decision making processes be fully transparent and that priorities are established which reflect the most critical or sensitive conservation threats and management concerns of each individual fishery. In this context, the ICAMS approach is designed to establish priorities for individual or, groups of similar, fisheries. It is not the intent that this process be used as a substitute or replacement for the consultative processes and structures that define the overall fisheries management priorities of the DFO.

In fisheries management, the ICAMS approach requires that the fishing industry assumes the responsibility and accountability for the monitoring processes in order to ensure the sustainability of the fishery resources (conservation) and achieve the socio-economic objectives (management) of fisheries plans. The "Code of Conduct for Responsible Fishing" is consistent with this approach since many of the principles outlined in the "Code" support the position that the industry assumes more responsibility for monitoring and verification of its activities. It must be recognised however, that DFO as the regulatory agency retains control through auditing and enforcement functions therefore, providing reasonable assurance of compliance with the conservation and management provisions of the individual IFMP.

2.2 Changing responsibilities and roles

Stewardship of the resource has historically been seen as the sole responsibility of government. Given the complexity of the current management process and the associated workloads it is necessary that a proactive approach be taken to monitoring and the verification of activities that can threaten the sustainability of the fishery resources.

Traditionally, the government role in fisheries compliance has been defined as monitoring, control and surveillance (MCS). In the ICAMS approach the responsibility for monitoring, where appropriate, would be moved to the fishing enterprise. This reassignment of responsibility would provide the regulatory agency with the opportunity to focus its efforts and direct its resources to the auditing functions required to ensure compliance. In some instances, verification could also be a responsibility of the regulatory agency.

The adoption of risk assessment, threat analysis and critical control point principles, to fisheries management, can assist managers in determining priorities within individual fish management plans and in directing resources towards the most critical resource conservation and fisheries management concerns. The ICAMS approach can provide a framework for fisheries monitoring and verification, detection of non-compliant activities and ultimately the deterrence of undesirable activities and practices that can negatively affect the sustainability of the fisheries resources.

3 HAZARD ANALYSIS AND CRITICAL CONTROL POINTS (HACCP)

The ICAMS approach to fisheries management and monitoring programmes is based on hazard analysis and critical control points (HACCP) principles, which were developed for the food processing industry (Annex 1). HACCP is a logical business approach to the orderly conduct of a highly regulated industry. The focus in the food sector is on industry monitoring of the processes that are used to eliminate potential hazards to human health.

The use of an adapted risk assessment system is a logical process that can be applied to the management, monitoring and control requirements of any regulated industry. Although, the current application is primarily directed to the food processing industry, many aspects of the HACCP philosophy and principles can be integrated into broader quality assurance based programmes for any industry activity. The application of this approach to the existing fisheries management process within the DFO is being considered as a mechanism that could contribute to the further evolution of the IFMP process, particularly, as it relates to the development of management plans for individual fisheries or groups of similar fisheries.

There are a number of essential similarities between the fish processing and fish harvesting industries. Both industries are directed by the private sector, both are highly regulated by government agencies, and both are undergoing conversion to accepting increased responsibility for monitoring and compliance activities.

The HACCP system as applied to the food processing industry requires that private sector processors assume responsibility and accountability for their activities and results. In the fish harvesting sector however, the responsibility and accountability for the conduct of the participants has traditionally rested with the government regulatory agency. Essentially, the DFO has established, over time, a highly complex management and enforcement regime that places the responsibility for ensuring compliance with the department i.e. the DFO is required to detect, apprehend and prosecute violators.

The HACCP system was developed by NASA for space programme applications in the early 1970s. Since that time it has been used to identify and eliminate human health hazards in the food industry. In recent years it has become the international standard under which production and trade in food products takes place.

The system is based on the principles of hazard analysis, programme monitoring, detection of non-compliant activities and ultimately the deterrence of activities and practices that can result in food safety hazards to consumers. The system is also used to control other probable and potential deficiencies in food production and distribution including commercial and economic fraud.

An important consideration in the risk assessment or threat analysis approach is the responsibility and accountability demanded of the stakeholders. The companies involved in the production and distribution of the food product are responsible for all aspects of the programme with a particular emphasis on monitoring and verification activities with audit remaining the prerogative of the regulatory agency.

Within the food processing industry, this is not a voluntary compliance programme. Rather, the requirements for a strong monitoring programme, an effective verification process and an audit and regulatory regime are legislated with processors required, by law to implement the programme.

The primary benefit of a risk assessment styled approach to fish harvesting is its capability to provide regulators and managers with the tools required to deploy resources to those areas or issues which are of primary concern to that regulatory sector.

The HACCP principles are based on the orderly conduct and regulation of the food production industry and are focused on an analytical approach to business. In food production, the monitoring and verification functions are the responsibility of industry. However, the regulatory control or audit function remains with the regulatory authority.

Experience in the food processing industry has demonstrated that the introduction of these principles promote better communication and trust between the private sector, regulators, the scientific community and the general public bringing benefits to all stakeholders. It has also become the preferred mechanism for reducing or eliminating barriers in international trade in foodstuffs.

Table 1. A comparison of hazard analysis critical control point (HACCP) and integrated conservation and management system (ICAMS) principles.

Principle	HACCP	ICAMS
Principle 1	Identify the potential hazards	Conduct analysis of the fishery.
Principle 2	Determine points, procedures and operational steps.	Identify conservation and management threats, action points and measures.
Principle 3	Establish critical limits associated with each hazard.	Establish critical limits associated with each conservation and management threat.
Principle 4	Establish a monitoring system.	Establish the monitoring system.
Principle 5	Establish the corrective action.	Establish corrective action plan.
Principle 6	Establish procedures for Verification.	Establish verification processes.
Principle 7	Establish documentation Procedures.	Auditing and Enforcement actions.
Principle 8		Documentation and recording keeping.

There are seven (7) HACCP principles that were established for the food processing industry. Analysis of the application of the concept to fisheries management has resulted in the establishment of eight (8) principles for the Integrated Conservation and Management System approach to the Integrated Fishery Management Planning process. The additional principle is the result of the requirement to modify the sixth HACCP principle; verification. Within the fisheries management context it is necessary to include, in addition to the verification function, the auditing and fisheries enforcement functions. A comparison of the HACCP and ICAMS principles is outlined in Table 1.

3.1 Application to fisheries management

The adaptation of similar risk assessment principles, to fisheries management, can assist managers in determining priorities and in directing resources towards the most critical resource conservation and other fisheries management concerns. It can also be more cost efficient in that stakeholders assume more responsibility for monitoring and verification. The ICAMS approach can provide a management framework based on the principles of threat analysis, programme monitoring and verification, detection of non-compliant activities and ultimately the deterrence of undesirable activities and practices that could negatively effect the sustainability of the fisheries' resources.

The prerequisite for entry to this process within fisheries management would be, as a minimum, a fishing enterprise holding a valid fishing license and actively participating in a commercial, recreational or aboriginal fishery in Canada or licensed to participate in fisheries regulated through international bodies such as the north west Atlantic fisheries organisation (NAFO) or the International commission for the conservation of Atlantic tuna (ICCAT) -. Conversely, this approach can not be applied to activities such as unlicensed fishing (poaching) and persons fishing illegally in closed times and areas. These are individuals for whom partnering, using this approach is not practical.

It is also intended that this approach be applied to individual fisheries or groups of similar fisheries. The process would be used to determine conservation and management priorities and assign resources within a fishery or group of similar fisheries. It is not intended to replace existing consultative and advisory structures that define the broader management priorities of the DFO.

4 THE PRINCIPLES OF AN INTEGRATED CONSERVATION AND MANAGEMENT SYSTEM (ICAMS) APPROACH TO FISHERIES MANAGEMENT

4.1 Conduct an analysis of the fishery

1. Define the scope of the fisheries management plan;
2. Collect all relevant information regarding the species (intended use, participants, fleet sectors, processors, other), stakeholders (gear types, fishing areas and seasons, history of landing and values) and all other relevant aspects of the fishery;
3. Describe and evaluate the effectiveness of previously applied conservation and management measures, and threats;
4. Assemble a working group/advisory committee, and
5. Establish the work plan for the development and implementation of the Integrated Fishery Management Plan (IFMP).

4.2 Identify the conservation and management threats, action points and measures (Annex II)

1. The science programme should be responsible for the initial description of the conservation threats, the most appropriate action points and the conservation measures that may be applied;
2. The descriptions of the conservation threats, action points and measures should be included with the stock assessment and biological advice;
3. Identify the management threats, action points and measures;
4. Fishery management should be responsible for the initial description of the management hazards, action points and measures;
5. Conservation and management threats, action points and measures should be confirmed by the working group/advisory committee;
6. Identify, with the working group/advisory committee, the most appropriate fisheries conservation/management measures and techniques that will be used to minimise the risk associated with each conservation and management threat, and
7. Identify the action points where the conservation or management measures would be most effectively applied.

4.3 Establish critical limits associated with each conservation and management threat.

1. Prioritise the conservation and management threats;
2. Determine the level of risk associated with each threat i.e. the potential impact to conservation of the stock and management of the fishery (high, moderate, low);
3. Determine the level of risk associated with each of the proposed fishery conservation and management measures (high, moderate, low);
4. Identify the critical limits associated with each preventative conservation and management threat and measure;
5. Describe the application of the conservation and management measures in the format of a fishery management plan, and
6. Establish the requirements for the development of compliance-related activities; monitoring, verification and audit and enforcement of the "Integrated Fishery Management Plan".

4.4 Establish the monitoring system.

Government has historically assumed the responsibility and accountability for the implementation of the monitoring, control and surveillance system in Canadian fisheries. Within the ICAMS approach the fishing industry accepts responsibility and accountability for monitoring their individual actions relative to the approved integrated fisheries management plan.

If, for example, the IFMP identifies as a conservation threat, the potential capture of juvenile fish, the conservation measure (CM) to deal with this issue could be the introduction of an increased mesh size for gillnets. The conservation action point (CAP) of the monitoring strategy could be the implementation by individual fishers of a self directed monitoring programme which could include the measurement of all or a sample of the gillnets prior to the commencement of fishing. Another CAP could also be the measurement of the nets prior to purchase. A similar strategy would be adopted for each management threat, measure and action point (MAP).

The individual monitoring system would require the fisher to maintain records each time the gear is measured, therefore, confirming that the gear conforms to the regulated mesh size. In this case, problems with gear size can be identified before they can become conservation threats.

This process requires that the individual fisher take responsibility for monitoring the measures contained in the IFMP thus ensuring compliance. This fundamental fishing enterprise approach to monitoring significantly changes the manner in which fisheries enforcement is carried out in most fisheries.

Although the traditional, role of government in fisheries compliance has been defined as monitoring, control and surveillance, this concept defers the responsibility for monitoring to the fishing enterprise. Implementation of this approach requires that participants;

1. Identify the level of monitoring required to achieve the critical limits of each threat and measure at each CAP and MAP;
2. Determine the most effective monitoring activity and frequency required to achieve compliance at each CAP and MAP;
3. Determine who in the fishing enterprise will have responsibility for monitoring the conservation and management measures at each CAP and MAP. For example, a specified crew member, and
4. Recognise that the license holder is at all times accountable for the monitoring process.

4.5 The corrective action plan

A corrective action plan should be developed by the fishing enterprise and should specify the actions that will be taken if the results of the monitoring process indicate that the critical limits established for specific conservation and management measures have been exceeded (e.g. if 10% of the gillnets are less than the regulated mesh size).

The corrective action plan must outline for each measure written details specifying the immediate action to be taken, those to be notified, the form of the report, and other relevant details in the event of implementation.

The corrective action plan should establish an investigative process which should determine, how the loss of control occurred, how a potential re-occurrence can be prevented and detail the corrective action which was taken.

4.6 Establish the verification process

Verification is a fundamental principle of the ICAMS approach. The verification approaches must be designed to ensure that industry monitoring programmes achieve their objectives and that fishing enterprises are in compliance with the conservation and management measures described in the IFMP.

The verification function can be assigned either to industry or government or can be shared between both parties. The assignment of the verification function should be based on the significance and sensitivity of the conservation or management threats and the monitoring process that would be proposed by the industry and approved by fisheries management.

The organisational structure of the industry, i.e. the association, group or community of fishing enterprises that would carry out the verification function would also be an important consideration.

4.6.1 Industry directed verification

The verification function could be assigned to an association, group or community of fishing enterprises, which has the demonstrated capability to ensure that its members would comply with the provisions of the IFMP. In this case, the verification process could be directed towards monitoring activities that have little or no impact on conservation but rather would reflect the social and economic objectives requested by industry.

4.6.2 Shared verification

The verification function could also be shared with government depending on the risk to the resource or the nature of the threat. In such circumstances where a potential conservation threat is recognised the proposed monitoring programme and the organisational structure of the industry should be such that the verification function could be shared. (e.g. the verification of monitoring activities related to escape mechanisms in lobster traps).

4.6.3 Government directed verification

Government would assume the verification function in circumstances where a significant conservation threat exists or in the absence of an industry association or similar organisational structure. For example, where highly sensitive conservation issues such as dumping, discarding and high grading of catch were evident DFO would maintain control of the verification process. In cases where monitoring is assigned to individual fishing enterprises the absence of a cohesive collective organisational structure would also require that DFO assume the verification function.

All verification processes could take the form of an inspection of the monitoring records of individual enterprises and/or the inspection of vessel, gear and catch.

The verification plan could contain information on how the verification process would be implemented, the frequency of the inspections and the records to be kept. It would also detail those to be informed when critical limits are exceeded and the remedial actions to be taken in the event of violations, i.e. sanctions. The plan should also facilitate requests from the industry for a DFO investigation.

4.7 Auditing and enforcement actions

The auditing function is solely the responsibility of the regulatory agency or government. This is essentially the independent evaluation of the approved monitoring and verification process, where the verification process is undertaken by industry. The form of the audit should be determined by government and could include forensic or financial audits.

The audit function also includes surveillance and enforcement actions by DFO staff. Directed sea, air and land based surveillance and enforcement actions, including at sea boarding and dockside inspections of vessels, gear and catches etc. are essential components of the fisheries auditing and enforcement programme.

4.8 Documentation and recording keeping

The primary component of the industry monitoring and verification process is the effective documentation of required monitoring activities for each conservation and management measure at designated CAPS and MAPS. For example, records may be required for all CMs and CAPS but might only be required, by exception, for management measures (MMs) and MAPS.

Individual fishing enterprises would be required to maintain records and documentation of the monitoring and corrective action processes. Associations, groups or communities involved in verification must also keep similar records. Access to these records could provide the regulatory authority with an industry or individual profile that would enable it to focus enforcement and surveillance activities on those issues and fishing enterprises which have a significant potential to negatively impact the sustainability of the fishery or its orderly conduct.

4.9 Terminology

Annex III provides a glossary of terms that can be applied to the Integrated Conservation and Management System (ICAMS). The definitions have been adjusted to reflect the fisheries management context. The glossary does not attempt to redefine current fish management activities and terminology. Annex III is not definitive but is intended to provide the reader with interpretations of the ICAMS approach as it applies to fisheries management.

5 ROLES AND RESPONSIBILITIES

Historically, the roles and responsibilities of the regulatory agency and the fishing enterprises in the fisheries management process have been fixed (Table 2).

Table 2. The roles and responsibilities of the regulatory agency and the fishing enterprises in the fisheries management process.

Role	Current Responsibility	Responsibility Under ICAMS
Enacting Legislation and Regulations	Government	Government
Setting Public and Fisheries Policy	Government	Government/Industry
Establishing Management Plans	Government/Industry	Government/Industry
Monitoring	Government/Industry	Government/Industry
Verification	Government	Government/Industry

Auditing/Enforcement	Government	Government

By virtue of its legislative mandate the regulatory agency retains control of all elements of the management process. The role of the fishing enterprise is relegated to the provision of advice and the harvesting of the resource.

In the ICAMS concept the fishing enterprises would be assigned increased responsibility for the monitoring and verification functions of the various IFMPs. This would have the effect of concentrating the regulatory agency role toward some verification and all auditing functions.

Fishing enterprises would be responsible and accountable for monitoring their individual compliance performance. This can be considered as the first step in establishing an effective conservation ethic for a self-reliant fishing industry.

Involvement in the monitoring function also requires the fishing industry to participate, actively and effectively, in the identification of conservation and management threats, management measures and action points. It can be anticipated that the requirement for industry monitoring will lead to the development and implementation of less complex and more cost effective monitoring and verification processes.

The role of the fishing enterprises in the IFMP is modified from advisory to ongoing participation in all components of the IFMP that affects the individual fishing enterprise's economic viability.

Assignment of the monitoring role to industry would permit the regulatory agency to direct its resources to auditing functions. In addition, the regulatory agency could direct additional resources to specific conservation threats and measures that could not be assigned to industry because of the sensitivity of the threat and the impact it could have on the sustainability of the fishery.

Internally, the roles of the various DFO programmes may not require significant modification and the current roles have been designed to compliment the IFMP process. The provision of advice and the development of the IFMPs would remain the essential roles of the science and fisheries management programmes.

The most significant changes would occur in the responsibilities of each programme (Table 3). The ICAMS approach requires that the individual programmes complete specific components of the IFMP. For example, science could be responsible for articulating the conservation threats, management measures and action points. Fisheries management could articulate the management threats, management measures and action points (Table 2). The process of developing the IFMP in terms of activities i.e. analysis, advice and consultation, is compared in the context of the existing approach and ICAMS. Both processes result in the completion of the IFMP. However, the ICAMS approach clearly, describes and prioritises the conservation and management threats, management measures and action points. This level of detail in the IFMP is essential to the effective development and implementation of the monitoring, corrective action, verification, audit and documentation processes.

The focus of ICAMS is directed primarily on those actions that are included in monitoring, control and surveillance activities. However, the shift of responsibility to the fishing enterprises for the monitoring function requires increased emphasis on the verification and audit functions of government.

6 CONCLUSIONS

Prior to the implementation of hazard analysis to the fish processing industry the emphasis on fish inspection was directed towards end product inspection. Little, if any, effort was directed toward the preventative aspect of risk assessment and its potential impact on compliance. A similar situation currently exists with the fish harvesting sector and fisheries enforcement. While many fisheries enforcement activities are directed towards prevention through deterrence, there are also many which are directed towards apprehension after the offence has occurred. Apprehension after an occurrence, for example dumping or high grading, will not directly contribute to the sustainability of the fisheries resource. Therefore, emphasis must be placed on the prevention of such undesirable harvesting practices. The ICAMS approach, which emphasises preventative measures and supporting monitoring and verification processes, is a logical extension of the current Integrated Fish Management Planning (IFMP) System.

Table 3. The development of an integrated conservation and management system (ICAMS) approach from existing integrated fisheries management plans (IFMP) and management activities.

IFMP Guidelines	Management Activity	ICAMS Principles
Overview of Fishery	Analysis	Conduct Analysis
Stock Status	Scientific Advice	Identify Management Threats & Measures
Management Advice General Management Objectives	Management Advice	Identify Management Threats & Measures
Current Management Issues	Consultation	Establish Critical Limits
Management Issues	Fishery Management Plan	Proposed Fishery Management Plan
Enforcement Issues & Strategies	Monitoring Control and Surveillance	Monitoring System Corrective Action Plan Verification Process Auditing and Enforcement Documentation

As previously noted the IFMP process evolved to ensure that there was effective input to the fisheries management process. The extent to which this process has been effective in achieving full integration remains uncertain. This may in part be attributed to the use of guidelines rather than principles as the criterion used to develop such plans. Guidelines are clearly guidelines. Consequently they are open to individual interpretation and application. Guidelines therefore, lack the rigour and discipline that can be achieved through the use of principles, such as those described in the ICAMS approach. The Integrated Fishery Management Planning process (Annex IV) shows that there are some similarities between the IFMP process and the ICAMS approach. The planning and consultative elements are similar. However, the ICAMS approach attaches more discipline to the threat analysis and preventative measure components than does the IFMP.

The ICAMS approach focuses, through the application of principles, on the identification of conservation and management threats and action points as the primary method of developing the IFMP. The ICAMS approach requires that each principle be thoroughly analysed and addressed, introducing a significant level of discipline and rigour into the fisheries management decision making process and providing a better framework for a due diligence defence in litigation than would be available under the application of the guidelines described in the IFMP approach.

The major difference between the current IFMP approach and the ICAMS approach occurs at two levels. Firstly, the requirement for the specific analyses to identify conservation and management threats and action points. The approach focuses the IFMP process on the conservation threats and actions points that ensure the sustainability of the resource in the first instance and thereafter at the monitoring, control and surveillance level. The ICAMS approach transfers to the harvesting sector the responsibility for the monitoring function and therefore, the accountability for its fishing practices. The department's role should be clearly focused on the verification and auditing functions that ensure industry compliance with the provisions of the various IFMPs.

The ICAMS approach, as proposed, can therefore, provide the rigorous decision-making framework that is required to achieve the new objectives of fisheries management.

7 THE POTENTIAL BENEFITS OF AN INTEGRATED CONSERVATION AND MANAGEMENT SYSTEM APPROACH

The proposed ICAMS approach provides the following benefits for the DFO and the fishing industry. The ICAMS approach:

1. Provides for access to the decision-making process through the existing "Integrated Fish Management Plan" process;
2. Provides for a consistent and rigorous decision-making process that can address all the conservation and management concerns in integrated fish management plans;
3. Describes the principles that provide a consistent framework and methodology for decision making and establishing priorities for fishing plans;
4. Provides for an analytical framework for the implementation of multi-year fishery management plans;
5. Provides for a framework for the effective involvement of the harvesting sector in all aspects of the "Integrated Fish Management Plan" process;
6. Provides for a framework and methodology for the harvesting sector to develop monitoring and verification processes and strategies for inclusion in its conservation harvesting plans;
7. Upon adoption is comparable to the establishment of a quality assurance/control process for fisheries management. This has an impact similar to introducing a total quality assurance programme;
8. Provides an opportunity to direct resources toward those measures that have the potential for greatest impact on the sustainability of the fishery, allowing maximum utilisation of existing resources in consequence;
9. Provides for an increase in the responsibility and accountability of all players in the IFMP process;
10. Provides for an effective due diligence defence if a significant event, such as collapse of a fish stock, were to occur through the rigorous application of the standards and principles contained in the ICAMS approach, and
11. Compliments the development and implementation of the "Code of Conduct for Responsible Fishing".

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