Measuring the Abundance as a Basis for Fisheries Management

A review of the most common scientific methods to assess the abundance of bottom fish populations

By Tore Strömme

At independence Namibia, as one of the last nations in the world to claim its own territorial waters, declared an exclusive economic zone (EEZ) of 200 nautical miles. Until then, the fishery resources had been open to an international fishery managed through the International Commission for the Southeast Atlantic Fisheries (ICSEAF). The reported catch data were analysed with mathematical models of correlating stock size and fishing pressure. This correlation was the basis for management advice and was used to set the total allowable catch for the fishing nations operating in the region.

Reported catches in the late 1980s were consistently 100 000 tons below the recommended total allowable catch (TAC) and stocks kept on declining, a sign that the total allowable catches and the fishing pressure were too high.

In 1990, Namibia started a programme to allow the fish stocks to recover. The Norwegian Agency for Development Cooperation (NORAD) made available the research vessel Dr Fridtjof Nansen and scientists from the Institute of Marine Research in Norway to assist Namibia in this task. The main purpose of the Norwegian assistance was to provide information on the state of the resources so that the planned expansion of the Namibian fishing industry would be within the limits biological production could sustain.

The pre-independence data of hake catches were not considered reliable for any analysis. Namibia needed to determine the state of the stocks by using scientific survey techniques. In the following six years of research until June 1996, thirteen hake surveys were carried out. This work was combined with the training of Namibian scientists in survey techniques and analysis.

In the first years the surveys reported a rapid increase in hake stocks, an increase also reflected in the success of the fast expanding fishing industry. However, in 1993 a stagnation in growth was observed, followed by a steady decline. In 1996 the biomass of adult Namibian hake was at the same level as at independence. Because of the gloomy reports of declining stocks, the survey research work came under scrutiny and the industry hired independent consultants to provide alternative assessments and to evaluate the reliability of the research methods in use.

The data and analytical tools from the pre-independence period indicated much higher biomass estimates than those obtained through the surveys. While the survey methods were reporting a gradual declining parent stock of Namibian hake, the analytical model showed a very healthy stock close to the limit of the carrying capacity of the Namibian shelf. The conflicting results on the state of the stock generated great uncertainty in the management sphere and in the Namibian fishery sector as a whole.

The Norwegian Agency for Development Cooperation (NORAD) made available the research vessel Dr Fridtjof Nansen and scientists from the Institute of Marine Research in Norway to assist Namibia in the assessment of the state of its fish stocks.
Why this article?
This article attempts to clarify the issue by reviewing the various tools scientists have at hand for evaluating the state of demersal stocks, such as hake. It will compare the advantages and drawbacks of the various methods and discuss their applicability to Namibian fish stocks. The review aims to contribute to the dialogue between scientists, managers and the fishing community at large. The article concentrates on research tools for the bottom-living species.

After independence trawl surveys were the most important method used for assessment of Namibia’s demersal fish stocks and this method will be dealt with more extensively. Abundance estimates of pelagic species, living mostly in the upper water masses, require different tools and methods, of which the acoustic method is the most important and the most common. As hake is at times also found off the bottom, the acoustic method is also used in the assessment of these stocks and will be briefly mentioned in this review.

Why fisheries management?
Scientists and the fishing industry consent that modern industrial fishing can be detrimental to the very foundation the exploitation of its ocean resources is based on. Examples abound of fish stocks harvested down to just a fraction of their potential. In several cases fisheries collapsed, leaving fishing communities in economic and social crisis. The present situation on the eastcoast of Canada is such an example.

Aquatic environments that have been emptied of their fish resources usually continue to be highly productive. However, man because of the low abundance of fish cannot harvest the biological production. The situation can be compared to leaving rich grazing land unused by herds.

The social and economic impact of overfishing is a classical example of how rational behaviour by an individual can result in large-scale detrimental effects when many follow it. For the individual fisherman it might be profitable to keep on fishing even when the resource level is low and the regeneration of the resource is at stake, as his individual behaviour does not add much to the situation. Any spared fish would probably be fished by somebody else anyway. This conflict between the individual and the common good is as old as human societies and is in fact the main rationale for the creation of management institutions.

The global need for management of natural, renewable resources is more recent. It arose as a result of the development of highly efficient exploitation techniques, on the one hand, and of the pressure exerted by an increasing world population, on the other. Without strong management of the fishing sector, the resources will be heavily exploited and reduced to a mere fraction of their potential.

Why fisheries research?
Fisheries managers need to take into account the biological, social and economic effects of alternative harvesting strategies in order to maximise benefits from the exploitation of the resource. Reliable information is needed on the state of the resources and on their dynamics in order to set sustainable harvest levels. In particular, information should focus on the present size of the resource, its biological characteristics, namely, how fast it grows and reproduces. The short- and long-term effects of a given fishing effort are key elements in managing a resource.

This information should be obtained through the systematic collection and analysis of research data to enable the forecasting of scenarios on the basis of the present situation and past trends. Without such information, managers responsible for the preservation of renewable resources can rely only on their gut feeling or intuition, and can easily yield to the pressure of lobbying fractions and their often short-term economic interests. In the worst case scenario wishful thinking determines management.

Good research requires reliable data and skilled scientists, which are not always at hand. Furthermore, biological models cannot adequately describe the complicated processes of nature. This makes research vulnerable to the criticism from hostile quarters (often the fishermen themselves!) who use these weaknesses as evidence for a lack of reliability of scientific advice provided by research institutions. The solution to poor research is, however, not less research, but a renewed effort to improve the existing situation.

Scientists are seldom challenged when they report that fish stocks are increasing. This information is always welcomed and scientists’ work appreciated by most parties. The discrepancy in views usually arises when research scientists report that fish stocks are declining and alternative, more optimistic findings of the situation are proposed by the fishing industry. In all fishing nations of the world, there are examples of the private sector tending to be optimistic about fish stocks when stocks are declining and proposals are put forward to reduce the total allowable catch (TAC). This is understandable, considering the heavy investments and the many jobs often at stake. However, the information provided by scientists, although often unpopular, is less biased than the opinion of industry and should be considered the most important reference for decision making.

Brief overview of the available research tools
There are two different primary sources of data when assessing the state of a fish stock:

- the catch and effort statistics from the fisheries, sometimes complemented with biological information from catches or landings;
- data from specifically designed surveys.

Various methods are used to collect fisheries data. These include:

- monitoring the trends of catch rates, namely catch per unit of effort analysis (CPUE);
- investigating the historical link between total annual yields and annual fishing effort and advocating a long term yield and effort based on the model of this relevance, i.e. surplus production models;
- monitoring the age composition of the fish in the catches and following a yearclass of fish through catch records from the time it enters the fisheries until it dies and reconstructing patterns of growth, natural mortality and fishing mortality in a fish stock and advocating sustainable harvest levels. This method is called virtual population analysis (VPA).

The fisheries data independent methods, consisting of direct observation of abundance through surveys, use the same statistical method as in opinion polls, which are so
widespread today. By assessing the abundance and size structure of fish living at a few but statistically selected geographical points one is able to describe the situation of the whole population. Trawl surveys are used for bottom fish. If the fish is off the bottom, acoustic surveys are used to assess the abundance. When the target species is both on and off the bottom, scientist may use a combination of the two methods as in the case of the Namibian hake investigations since 1991.

Analysis of trends in catch rates (CPUE)
All fishermen have experienced that on average the catch rates are higher when a fish stock is abundant compared to when the stock is low. However, the link between catch rates and fish abundance is not always direct. Analysis of catch per unit of effort examines trends in the mean catches of a fishing fleet. An increase in the mean catch rate of a fishery could signal to scientists that the stock is increasing. However, this could also be the result of the fishermen having become cleverer or having introduced more efficient gear. Such factors should be considered carefully when carrying out this type of analysis.

Another potential error in CPUE analysis is associated with the biology and behaviour of the fish. If a declining fish stock occupies its full area of distribution, the density of the fish will decrease and catch rates may reflect the new decline. But if the fish tends to retract into a smaller area, the densities in these locations may be more or less constant. As the fishing fleet would naturally concentrate in the areas of highest abundance, the so-called hot spots, catch rates would not reflect the changes in total abundance.

This phenomenon might also work the other way. When a fish stock is increasing it might expand its territory and the density in the traditional fishing areas will not necessarily increase. If the fishermen keep on fishing in the traditional fishing grounds, the increase in the stock might go unnoticed by both fishermen and scientists.

When new yearclasses of young hake in Namibia enter the fishing grounds they tend to do so in aggregations. The fishermen might interpret the densities in these aggregations as signs of an increase in fish abundance. It is, however, important to assess the extension of these aggregations, as abundance is the arithmetic product of fish density and area occupied. Density in itself or catch rates tell only half the picture of abundance, the distribution areas of the fish are as important.

Changes in catch rates might also be due to changes in availability. The fish might at times be easier to catch because of changes in behaviour, for instance when migrating to the spawning areas in dense aggregations. Also, it might temporarily lift off the bottom and become inaccessible to the bottom trawl causing a drop in the catch rates.

For these reasons, trends in CPUE cannot be used independently to assess the state of the stocks. However, if information on the stock outside the fishing areas is available and it is possible to monitor and compensate for changes in fishing efficiency and availability, CPUE analysis is a useful, relatively simple and inexpensive tool to indicate the state of the stocks. Nowadays CPUE analysis is used mainly to support more advanced methods. One of the main reasons for the collapse of the huge cod stock off Newfoundland in the early nineties was that scientists and managers relied too much on trends in the CPUE. These were in sharp contrast with survey results.
Establishing surplus production models from historical catch data

A 'virgin fish stock' is an expression indicating a stock in an unfinished state. Virgin stocks are often assumed to be in a steady state, neither increasing nor decreasing. In such a steady state condition, the fish entering the population through reproduction and the growth of the individual fish balance with the biomass lost because of natural death by predation or by aging.

When fishing is introduced in a virgin stock, the higher pressure on the population stimulates production because more food becomes available for the individual fish and because the remaining part of the population consists of younger individuals characterised by a faster growth than the older fish. The net production in the stock increases and man can harvest more. If the fishing effort continues increasing, the thinning out of animals will result in a level where there are insufficient numbers to use the food in the area and at a certain level the number of fish will be so low that reproduction is affected. A very low number of parents will give a low number of offspring and the stock may rapidly decrease. In this situation the production for human exploitation is very low. Between these two extreme situations there is an intermediate optimum effort level for fishing where the surplus production of the fish stock is at its maximum.

Through analysis of historic catch and effort data, scientists try to establish a mathematical correlation between the effort level and the surplus production, represented by the total catch from the fishery. This mathematical relation, expressed as surplus production model, indicates the long-term optimum combination of effort and annual catch for a fishery.

To produce such a model scientists need reliable historical data on both the effort and the catch. These data sets are sometimes difficult to obtain. They often need correction to compensate for changes in effort efficiency in the period considered, changes in the availability of fish and unreported as well as inaccurate catch figures.

The main weakness of the method is, however, more fundamental. By making a mathematical model of the reality one is forced to simplify nature by introducing assumptions. In most surplus production models one assumes that the natural conditions surrounding a fish stock are constant. This would concern factors such as the availability of food, presence of predators and competitors, environmental conditions affecting distribution, reproduction and recruitment. Biologists working in the field know from experience that these factors are anything but constant, and fluctuations may be both of short- and long-term nature.

The annual reproduction success of a fish stock is a complicated process under strong influence from environmental and biological factors, for example, fluctuations within a range of one to ten fold between years are not uncommon. When setting harvest levels for a fish stock, the number of recruits entering the fishery in the near future should be taken into account. Simple surplus production models do not provide such information.

Without more detailed information on the state of a stock, a surplus production model could give a rough indication of the potential of a fishery, but in most cases it is inadequate for year to year management.

Analysing the age structure of the catch through virtual population analysis (VPA)

In this method the yearclass is the central concept. A yearclass is all fish born in a particular year. This method follows the history of a yearclass from when it enters the fishery until it disappears in the catches because it is fished out or dies out from natural causes. One classifies fish into yearclasses by analysing earbones (otoliths) or fish scales which often show annual growth rings, or by analysing the length structure of the fish population. By combining the catch records with samples on the age composition obtained onboard fishing vessels or at the landing sites, one is able to estimate the number of fish caught of each yearclass in that year. When a yearclass no longer appears in the catches, we have a complete time series of annual catch data for the same.

Scientists use such time series to back calculate how many fish were in the sea when the yearclass first entered the fishery. Not all fish end up in the net of the fishermen and an assumption about the annual number of fish that die from natural causes is built into the back calculation model. When this procedure is repeated for several yearclasses, scientists can estimate the initial size of each yearclass and the fishing mortality through its life history. These fishing mortalities are then combined with the figures on fishing effort in a mathematical model to find the combination of effort and fishing mortality that maximises the yield.

This method allows us to quickly identify signals of sudden increase in the fishing mortality of the last years and countermeasures can be introduced before serious overfishing occurs.

The technique of reconstructing the history of a fish population through back calculation is called virtual population analysis, or VPA. It is the most widely used for demersal fish populations. The VPA includes several assumptions which put some limitations on its application. In the back calculations one assumes a constant natural mortality usually through the whole life span of the yearclass and no interannual changes in the natural mortality. This can cause serious errors as the natural mortality will vary with predator pressure, which in itself can show great fluctuations. Hake in Namibia is a cannibalistic species and young hake may, when available, form the main diet of the older fish. In such instances the natural mortality is largely determined by the relationship between the young and adult part of a highly dynamic population.

The VPA method shows only the history of past yearclasses and cannot be used to predict recruitment to the fishery when new strong or weak yearclasses arrive in the fishery. For example, very dynamic recruitment success of the Namibian hake can be considered as a random process within some limits. Therefore, VPA in its simple form is not suitable for short-term management of variable fish populations. In modern versions of the VPA method, using recruitment estimates from surveys and independent estimates of natural mortality compensates for these limitations. Modern VPA is an advanced method requiring a solid time series of reliable statistics, skilled personnel for age reading of the samples, intensive survey work and advanced computer programmes for comprehensive analysis. When all these elements are in place it is considered a robust method for monitoring and managing fish stocks. Namibia currently has
no such time series of data available for these studies. Skilled manpower for age reading of biological samples is also lacking. VPA analysis has been chosen as one of the future research tools for Namibian hake, but it will take at least five years before sufficient data are gathered.

Survey methods

The rationale of trawl surveys is quite simple. A series of trawl samples are taken from the investigation area, following a statistical sampling scheme. If one can catch all the fish in the bottom area swept by the trawl, the density of fish at the location is the ratio between the catch and the area covered. If one could assume that all fish, in this case all hake, at and above the bottom within the sample area are caught and that one can accurately measure the sampled area, one would have a very reliable measure of the fish density in that location.

Experience has taught that these ideal conditions rarely fit the real world. Several errors in the measuring situation will cause errors in our estimate. We may not catch the same amount of fish that was in the investigation area before the trawl arrived and we could have problems in measuring the actual area sampled. The various factors that might cause bias in the estimate of density are addressed below.

Several factors affect the number of fish caught in a sampled area. The fish are distributed partially in the water masses off the bottom, and the trawl samples only near the bottom zone. Fish could be herded into the trawl by the wires, the trawl doors or by the clouds of sand steered up by the doors. Another factor is that fish could escape over the headline, under the footrope, through the front meshes or to the side when the mouth of the trawl approaches.

The measurement of the sampling area can be affected if the effective length of the trawl haul is not measured correctly due to position errors or due to inexact timing of when the trawl is actually settled at the bottom, starts fishing, or because it lifts from the bottom during the trawling operation.

The measurement will also be affected if the width of the trawl is not measured correctly or it varies with depth and trawling speed.

In more than ten years of systematic research, the Institute of Marine Research (IMR) in Bergen (Norway) has worked towards minimising the effects of the error factors. In some instances they were highly successful while other areas still need much work. The Nansen Programme is transferring the IMR knowledge of standardised trawl surveys to hake research in Namibia.

Addressing systematic errors: Fish off bottom

Since 1991 the hake above the headline of the trawl are measured by acoustic methods and added to the bottom trawl estimates. By combining trawl data with acoustic data one is combining two indexes that need to be standardised to the same unit before they are added.

At present the survey uses measures of acoustic properties obtained from cod in the Barents Sea in this process. Hake and cod, which belong to the same family of fish, have very similar acoustic properties, which were confirmed by preliminary direct studies on hake. More accurate direct measurements of the acoustic properties of hake are planned in the near future.

In certain areas hake off the bottom cannot be recorded accurately as the fish is masked by dense occurrences of horse mackerel, mesopelagic fish or plankton. To date these pelagic zones have not been included in the estimates but can be given the values of cleaner neighbouring zones. However, dense recordings of mesopelagic fish or plankton close to the bottom occur only in a fraction of the area of the shelf and compensation would probably not add more than 5% to the total estimate.

Hake in the zone above the bottom are usually not the same size as the fish in the bottom trawl zone. Small fish tend to bait the smaller organisms in the pelagic zone while the larger hake eat mostly other fish caught in the bottom zone. Until recently the fish in the pelagic zone was assumed to have the same size distribution as in the bottom trawl. This error will result in an overestimate of large fish in the population. In future this should be remedied by more direct sampling in the pelagic zone.

Systematic error: Fish herding

This is associated with fish behaviour and various trials have been conducted to measure it. Cod in the Barents Sea has demonstrated that doors, sand clouds, warps and sweeps herd the fish towards the opening of the trawl. The effective trawl width for adult cod is assumed to be close to the distance between the trawl doors, while for the young cod the area between the wings is the effective fishing zone. In contrast to hake, cod is a very vivid species which swims fast and reacts quickly to stimuli. Hake seems to react slower and does not burst swim to the extent that cod does.

Preliminary investigations on hake indicate that the adults respond to the doors, warps and sweeps to a lesser degree.
First estimates indicate a herding effect of about 10% for fish above 40 cm, while no effect was measured with the smaller fish. Investigations in the field will continue.

So far the herding seems to be of minor importance for the biomass estimate on hake. Its effect leads to overestimation of the true biomass, i.e. the present estimates tend to be over optimistic.

**Systematic error: Escaping of fish**

Fish escaping is the most complicated factor to measure and over years intensive work has been undertaken. In Norway and Scotland work on this subject has included comparative trawling, multi-bag trawls, still camera and video. The special sampling trawls used by IMR and Dr Fridtjof Nansen have a small mesh size and selectivity is assumed minor for small hake and nonexistent for adults. Larger cod have escaped above the headline, while the smaller fish can try to escape under the footrope. Because of the slow reaction of hake, the escapement loss is assumed considerably smaller than for cod, even if it has not been monitored for hake yet. The Nansen Programme has recently invested in a towed instrument platform and video cameras to measure hake behaviour in relation to the trawl. Recent preliminary studies have not been successful because of low visibility in the water at the hake grounds. Future studies with acoustic instrumentation on the platform are expected to give better results.

Fish escapement is at present the highest uncertainty factor in the hake trawl surveys. There are no indications that the loss of hake through escapement is considerable. The situation could be the same as for the herding effect. In that case, the two effects would to some extent balance each other. Further investigation in the field will be given priority.

**Error factor: Length of the trawl haul**

This probably was a major source of error. In the past when surface logs were used, the length of the haul probably resulted in poor positioning and was a major source of error. The sinking time for a bottom trawl in the past was easily underestimated for the deeper trawl stations, which would lead to estimating a shorter effective trawling time at the bottom and thus underestimate the true biomass at the bottom. This has been fully remedied by recording the trawl length over the bottom with a GPS navigator, at the same time as SCANMAR trawl sensors determine the exact timing of the start of the effective trawl operation. Throughout the trawling operation, monitoring of bottom contact is performed with the same equipment.

**Systematic error: Width of the trawl**

In the past, the door width used to vary with the depth of the trawling operation or with the length of the wire out. Varying door widths would also cause variation in the wing spread and height of the trawl. IMR is now using a transversal constraining rope between the two warps about 130 m in front of the doors. In this way, the distance between the doors and the trawl geometry are kept constant, irrespective of depth.

**General remarks on the survey method**

Because of several uncertainty factors trawl surveys have in the past been considered as abundance indexes rather than absolute estimates. IMR is systematically addressing the error factors in trawl surveys and works towards obtaining an absolute estimate, at least for some species. Due to its slow and sluggish behaviour, hake is believed to be one of the species best suited for absolute abundance estimation. Although a better understanding of escapement in front of the trawl is necessary before results from hake trawl surveys can be considered as true absolute estimators, the present results are believed to be close to the expected absolute values.

But even when the results are only considered as indices of the stock situation, the trends in these indices give important information for fisheries management. In Namibia the time series obtained from 13 trawl surveys since 1990, shows that the 1996 spawning stock of hake is declining towards the level observed in 1990, a critically low level. Then strong measures were considered necessary and implemented in order to rebuild the production potential of the stock.

**Conclusion**

Since independence the surveys with the research vessel Dr Fridtjof Nansen have been the cornerstone of research on the hake stocks in Namibia. The uncertainties regarding the extent to which the results from the surveys can be considered as absolute estimates of the biomass, have been presented and should be considered with care. However, the trends shown in the time series are reliable. The main weakness, however, is that only one method for assessing the state of the stocks is available, perhaps with some rough additional support from analysis of CPUE indices in the fisheries.

Namibia has decided to use VPA as an additional tool in management of the hake resource. It is advisable that a systematic collection of relevant data is initiated as soon as possible. Because the Namibian hake stocks will continue to be highly dynamic, a strategy based on adaptive management is necessary. Direct observation through scientific surveys is the only tool available to closely follow the year-to-year fluctuations in recruitment and stock size. The continuation of the survey work in Namibia is therefore important, also after the withdrawal of the Dr Fridtjof Nansen from the region in the not too distant future.

**The author:** Tore Strømme is a fisheries biologist graduated from the University of Bergen in 1978. His combined interests in fisheries research and development issues soon led him to work with fisheries research in developing countries. Since 1979 he has been working worldwide with resource surveys in a global project, run by the Institute of Marine Research, Norway, and the Food and Agriculture Organisation (FAO) of the United Nations. Since 1992 he has been the main Norwegian counterpart in the hake investigations in Namibia with the research vessel Dr Fridtjof Nansen. He is a member of the research staff of IMR and has been the leader of the Nansen Programme since it was started in 1993.